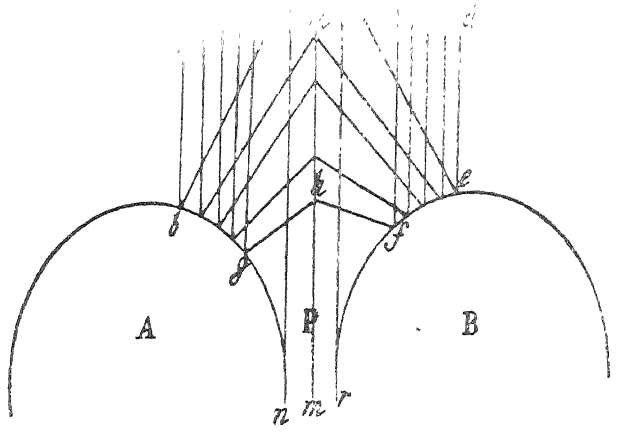
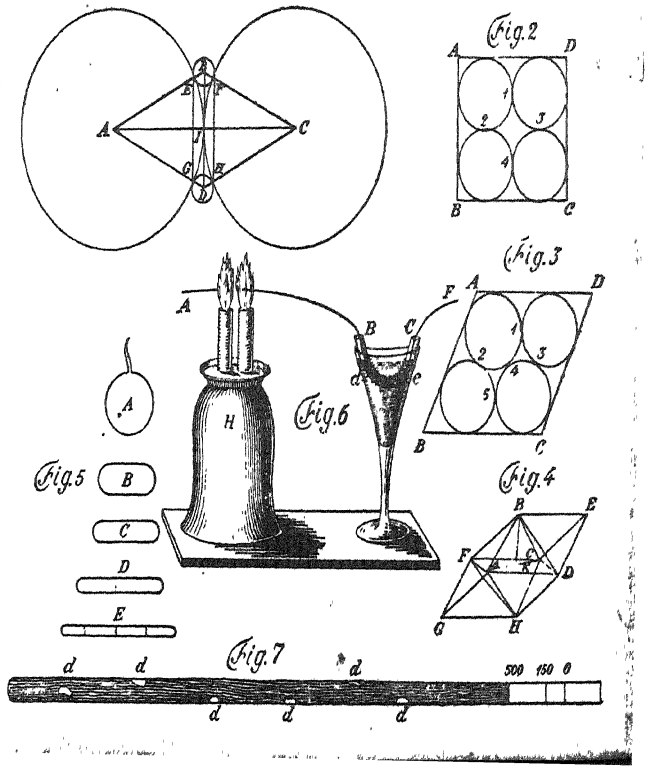


Mikhail Vasil'evich Lomonosov on the Corpuscular Theory

Translated, with an Introduction,
by Henry M. Leicester



M. V. Lomonosov was an eighteenth-century Russian polymath who worked in chemistry, physics, meteorology, geography, geology, and electricity, as well as philology and history. He was also a poet. Soviet historians of science regard him as the founder not only of Russian science but of much of modern science. Although his works have been published extensively in the U.S.S.R., Lomonosov's scientific theories are little known throughout the rest of the world, and much of the information about him that has accumulated in the literature is inaccurate.

In this book Henry M. Leicester presents translations of the papers on chemistry and physics in which Lomonosov developed his atomic (corpuscular) theories. In adapting the corpuscular theory of his day, Lomonosov in some ways went beyond such contemporary scientists as Boyle and Newton, and in other ways fell behind them. Thirteen of the fifteen papers are on the corpuscular theory, one is a sample criticism of his works, and the last is Lomonosov's answer to some of his critics. Each is published in English in its entirety for the first time.

In his introduction Mr. Leicester discusses Lomonosov's life and analyzes his scientific theories, examines the sources of his ideas, and considers the place of his corpuscular theory in the history of science.

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Mikhail Vasil'evich Lomonosov on the Corpuscular Theory

M. V. Lomonosov

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Translated, with an Introduction, by

Henry M. Leicester

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Preface

The works of Lomonosov are widely known and discussed today in the Soviet Union, but they have been much less studied outside the borders of that country. Fragmentary translations into Western languages have been made of some of the papers of this versatile scientist, but most of his writings are available only in the original Latin or in Russian versions. Russian historians of science have accorded him a high place in the development of their own science and have attributed to him the discovery of many laws which were later developed by other men. These statements have been disputed by historians of science outside the U.S.S.R. It therefore seems desirable to present Lomonosov's writings to a wider audience, so that a just estimate may be made of the significance of his work. Besides this, the intellectual ability of the man himself deserves to be better known.

The papers translated here admittedly show only one aspect of the thought of this polymath. His works in other branches of physics, in astronomy, geology, geography, mineralogy, meteorology, as well as his historical, philological, and literary activities must be considered by specialists in those fields. However, the papers presented here reveal clearly his remarkable originality and his ability to follow his theories to their logical ends, even though his conclusions were sometimes erroneous.

Most of Lomonosov's scientific works were written in Latin and have since been translated into Russian and published in the collection of his complete works in ten large volumes. The translations given here were first made from the Russian, and then compared with the Latin versions for greater accuracy in translation. I am, of course, responsible for any errors which have occurred.

I wish to express my thanks to Professor N. A. Figurovskii of the Institute of the History of Science and Technology in Moscow for generously supplying me with much of the source material which I have used. Thanks are due to Emanuel Davidove for his aid in translating certain of the eighteenth-century Russian terminology.

The frontispiece, a portrait probably painted in the 1750's, is

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taken from *Lomonosov Polnoe Sobrannie Sochinenii* (*Complete Collection of Papers of Lomonosov*), 10 vols., published by the Academy of Sciences, Moscow and Leningrad, 1951-1959.

Henry M. Leicester

San Francisco, California
August 1969

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Introduction

1. THE LIFE OF LOMONOSOV

Mikhail Vasil'evich Lomonosov[1] was born on November 8, 1711 (November 19, n.s.), in the village of Mishaninsk not far from Kholmogory, near the White Sea.[2] This region along the northern coast of Russia was separated from the rest of the country by vast forests and swamps, nearly impassible in summer, but easily crossed when frozen in winter. The inhabitants of this isolated region had never been exposed to the Tatar conquest nor to the institution of serfdom which had affected much of the rest of Russia. They were, however, in close contact with the foreign trade and traders, for their ports of Archangel and Kholmogory were the main gateways through which foreign goods from western Europe reached the Russians. As a result, most of the natives of this region, though classed as peasants, were far more independent and progressive than their counterparts in more southerly areas.

Lomonosov's father, Vasilii Dorofeevich Lomonosov, was the prosperous owner of fishing and trading vessels in which he carried on an active life at sea during the summer. In winter, the goods accumulated during the summer were sent in large convoys to Moscow to be traded for the materials needed by the northerners. Vasilii Dorofeevich's son was raised like most boys of his class to aid his father in fishing and trading, but he was early distinguished from most of his companions by his

1. There are many Russian biographies of Lomonosov reflecting the various phases of his career. These are in large part based on the lengthy biography by P. P. Pekarskii in *Istoriya Imperatorskoi Akademii Nauk v Peterburge* (Academy of Sciences Press, St. Petersburg, 1873), II, 259-892. The chief source in English is the translation of the biography by B. N. Menshutkin, *Zhizneopisanie Mikhaila Vasil'evicha Lomonosova* (Academy of Sciences Press, Moscow and Leningrad, 1937), which was published as *Russia's Lomonosov* (Princeton University Press, Princeton, N.J., 1952). This has been the source of the biographical details given here except as otherwise noted. Shorter accounts in English of Lomonosov are given by H. M. Leicester in *Great Chemists*, ed. Eduard Farber (Interscience Publishers, New York, 1961), pp. 201-210, and by Alexander Vucinich, *Science in Russian Culture* (Stanford University Press, Stanford, Calif., 1963), pp. 105-116.

2. This statement is given in *Letopis Zhizni i Tvorchestva M. V. Lomonosova*, ed. A. V. Topchiev, N. A. Figurovskii, and V. L. Chenakal (Academy of Sciences Press, Moscow and Leningrad, 1961), p. 17. Menshutkin, *Russia's Lomonosov*, following Pekarskii, does not mention the place of Lomonosov's birth, but states that his father lived in the village of Denisovka.

love for reading. At first the only books available to him were theological treatises obtained from nearby monasteries, and from these he learned to read the Old Church Slavic in which they were written. At the age of about fourteen, he obtained copies of two textbooks which were standard at that time, the *Slavic Grammar* of Smotritskii and the *Arithmetic* of Magnitskii. The first, in addition to grammar, contained instructions for writing verses, and the second included a survey of many sciences of the day. Young Lomonosov evidently absorbed from these much of the love of learning which characterized his later life.

Although the boy accompanied his father on the fishing and trading expeditions, he was not happy at home. His mother had died when he was still very young, and his father had married twice afterward, his second wife having also died early. The stepmother considered Lomonosov lazy because of his constant reading, and he reported later that he "was obliged to read and study, when possible, in lonely and desolate places and to endure cold and hunger." Therefore when he was nineteen, he resolved to go to Moscow to seek further education.

He left his home on December 7, 1730, and reached Moscow with one of the trading convoys in mid-January of 1731. Since he was legally classed as a peasant, he was not entitled to enter any of the better schools of the city; but he knew that he had to learn Latin in order to progress in any scholarly field. He therefore applied to the Slavo-Greco-Latin Academy, a training school for theological students. He represented himself as the son of a priest, and since he could read Church Slavic, his claim was accepted and he was admitted.[3] Here he progressed rapidly through three classes in one year and quickly became fluent in Latin.

Living conditions were difficult for the students, who were given a very small stipend with which to feed and clothe themselves, and Lomonosov's father refused to help him since he had not returned to engage in the family trade. Nevertheless, the library of the Academy contained books on philosophy which included much of the contemporary science, and Lomonosov eagerly studied these. His teachers were greatly impressed by

3. N. A. Figurovskii, *Lomonosov* (Znanie Press, Moscow, 1961), p. 6.

his ability, and even when they discovered his peasant origin, they did not prevent him from continuing his studies. However, they recognized that his interests did not lie in the direction of theological studies. When, in 1735, the head of the Imperial Academy of Sciences in St. Petersburg, Baron Korf, requested the school in Moscow to send twenty of its best students to study at the Academy, Lomonosov was the first choice. Only twelve students could be found, but these were duly sent, and on January 1, 1736, Lomonosov began his studies at the St. Petersburg Academy.

This Academy had been founded by Peter the Great in imitation of the Academies of Science in Paris and Berlin. Owing to the lack of Russian scientists, it had to be staffed by foreign scholars, and these had been chosen largely by Christian Wolff (1679-1754), the leading teacher of philosophy in Germany at the time. He had advised Peter during the formation of the Academy and was always interested in its activities. The Academy was formally opened in 1725, shortly after Peter himself had died. A number of political figures nominally succeeded one another as the head of the institution, but almost from the beginning the actual control was in the hands of Johann Daniel Schumacher (1690-1761), an Alsatian who had been Peter's librarian, and who became director of the chancellery of the Academy.

At the time Lomonosov entered the Academy, it was chiefly occupied in conducting great expeditions to discover and exploit the natural resources of Siberia, then newly opened to the Russians. Almost all the academicians who took part in this work were foreigners who received generous salaries and were supplied with excellent living accommodations.

Soon after Lomonosov reached St. Petersburg, the authorities of the Academy realized that no one trained in chemistry was taking part in any of the expeditions. They therefore requested Johann Friedrich Henkel (1679-1744), a leading German chemist and metallurgist then teaching at Freiberg, to recommend a suitable scientist for this duty. He reported that he knew of no one who was available in Germany, and therefor he advised them to send him students from Russia to study chemistry and mineralogy and so be ready for the next expedition. Baron Korf at once accepted the idea and ap-

pointed three students from the Academy to study in Germany. The three chosen were Gustav Reiser, Dmitrii Vinogradov, and Mikhail Lomonosov. Since it was realized that they lacked a proper background in science and philosophy, they were first sent to Marburg to study with Christian Wolff. Then they were to proceed to Freiberg to study with Henkel.

Accordingly, in the autumn of 1736 they reached Marburg and at once began to study German, philosophy, and physics under Wolff and elementary chemistry under J. G. Duising (1705-1761), the professor of medicine. The Russian students found much more personal liberty in Germany than they had at home, and they took full advantage of this, leading a rather wild life and incurring many debts. This latter fact was complicated by the failure of the Academy to keep up regular payment of their stipends, and Wolff was often obliged to give them financial aid. Nevertheless Lomonosov in particular was zealous in carrying on his studies, and his later work shows how greatly he was influenced by Wolff's teaching (see Chapter 2). Wolff in turn recognized the ability of the student, as is shown by the interim reports he sent to Baron Korf. Though Wolff was compelled to report on the dissolute lives and heavy debts of the Russian students, he and Duising still praised Lomonosov's diligence and learning. Thus, in August 1738, he wrote: "Lomonosov is evidently the brightest among them; he can be taught much by his great diligence and shows a great desire and wish to study."[4]

In 1739 the three students went to Freiberg to complete their studies with Henkel. Lomonosov certainly learned much of contemporary chemistry from Henkel, but found him a much less sympathetic character than Wolff. When funds failed to arrive from Russia, Henkel and Lomonosov quarreled continuously. In May 1740, Lomonosov left Freiberg and wandered for some time through Germany and Holland, trying to locate the Russian ambassador who, he hoped, could supply him with funds to return to Russia. He was unable to find him, however, and so returned to Marburg, where he lived with friends.

4. G. E. Pavlova, *M. V. Lomonosov v Vospominaniyakh i Kharakteristikakh Sovremennikov* (Academy of Sciences Press, Moscow and Leningrad, 1962), p. 96.

There, on June 6, 1740, he married Elizabeth Zilch, the daughter of a former city councilor of Marburg. The marriage was kept secret for several years, perhaps because he feared that the authorities would not approve of the foreign marriage. At last he was able to get in touch with the Academy in St. Petersburg and received an official recall to the capital. He reached it on June 8, 1741. It was not until 1744 that he felt able to send for his wife, who rejoined him in the summer of that year.

In spite of his difficulties in Germany, he had been able to complete several dissertations on scientific subjects, and to begin to compose the odes which later brought him fame as a poet. The high regard for his abilities attested by his favorable reports from Wolff, Duising, and even Henkel, made a deep impression at the Academy, and soon after his return he was made adjunct in the Class of Physical Science. His salary was 360 rubles a year, an ample sum at the time, but unfortunately the Academy had no funds to pay it, and so he was given the privilege of buying books at the Academy bookshop for a nominal sum and then selling them for whatever he could get.

Affairs at the Academy at this time were in a very confused state. Schumacher had been running the Academy in a very despotic fashion and had favored the German members at every turn. Russia was then governed by Biron, the incompetent favorite of the Empress Anne, but when she died the throne was taken by Elizabeth II, daughter of Peter the Great, and Biron fell from power. The enemies of Schumacher (and he had made many) were then able to attack him openly and finally bring about his arrest. Lomonosov sympathized with Schumacher's opponents, since as a patriotic Russian he felt that the German party had gained too much power in the Academy, and he believed that Schumacher himself was responsible for many of the difficulties which had occurred. His own position was not too strong, for he himself was engaged in quarrels with various employees of the Academy, sometimes resulting in physical violence. As a result he was placed under house arrest and was freed only after a public apology. Schumacher was soon cleared of the charges against him and resumed his former position of authority. After this, however, there was constant discord between the two men, and their

struggles for advantage greatly interfered with Lomonosov's later scientific activities.[5]

In spite of this, the years between 1741 and 1750 were extremely productive for Lomonosov, and most of his theoretical work in physics and chemistry and the development of his corpuscular theories were carried out during this period. In 1745, after completion of his paper "On the Luster of Metals," he was appointed Academician and Professor of Chemistry in the Academy. From this time on he was in a better position to challenge Schumacher's authority, and he frequently did so.

The enmity of Schumacher had one fortunate result for Lomonosov. The former had attempted to block Lomonsov's appointment as academician, and, failing in this, secretly sent several of Lomonosov's dissertations to the famous mathematician Leonhard Euler (1707-1783) in Berlin. He hoped that an unfavorable report on them would injure Lomonosov's career. Euler had been one of the first academicians in St. Petersburg, accepting an appointment in 1727. In 1741, just before Lomonosov returned to Russia, Euler had gone back to Berlin since he felt that the anti-German feeling in the Academy made his position there uncertain.[6] He remained in Berlin until 1766, when, at the request of Catherine the Great, he returned to Russia where he spent the rest of his life. He was always interested in the affairs of the Academy, and his established position lent great authority to any decision he made. His report on Lomonosov's dissertations must have been a great disappointment to Schumacher, for Euler wrote to Count Razumovskii, then the president: "All the communications are not merely good, but excellent, for they explain most needed and difficult physical and chemical matters which have been entirely unknown and inexplicable to the most intelligent learned men, with such soundness that I am completely convinced of the accuracy of the demonstration. In this case I do justice to Lomonosov, for he is endowed with most fortunate ingenuity in explaining chemical and physical phenomena.

5. For a detailed account of the state of the Academy at this time and of the quarrels between Lomonosov and Schumacher, see B. G. Kuznetsov, *Lomonosov, Lobachevskii, Mendeleev* (Academy of Sciences Press, Moscow and Leningard, 1945), pp. 19-40.

6. Vucinich, *Russian Culture,* p. 96.

We must hope that all the members of the Academy can display the ingenuity that Lomonosov does." When Lomonosov learned of this estimate, he wrote a grateful letter of thanks to Euler, and this initiated a correspondence which lasted for the rest of Lomonosov's life. Some of his most important results were first communicated to Euler and thus reached the world of Western science.[7]

During most of his early years in the Academy, Lomonosov had to carry out such experiments as he could in his own home, and thus many of his early papers lack any experimental descriptions. He applied constantly to the authorities for funds to build a laboratory, but it was not until 1748 that he was able to erect a chemical laboratory to his own specifications. Thus was built the first laboratory in Russia to be devoted to pure and applied research in general chemistry.[8]

After the construction of this laboratory, Lomonosov turned his attention to more practical problems, especially the preparation of various pigments, and then of colored glasses. He had always been interested in optics, and in this connection he developed his theories of color which were among his last important works in corpuscular theory. However, with the development of various colored glasses he became interested in their use in making mosaic pictures. He devoted much time to testing various mixes to make all shades of mosaic glass, and the work of the laboratory centered on this activity.

In 1753 he received permission to manufacture these colored glasses, and accordingly he built a factory at Ust Ruditsky. After 1755 much of his time and energy were taken up with the operation of this factory. He was very successful from a technical and artistic standpoint, but financially the plant was a failure, and for the last ten years of his life it kept him constantly in debt. In spite of this, he designed and built a large

7. The exchange of letters is given by V. L. Chenakal in *Lomonosov Sbornik Statei i Materialov* (Academy of Sciences Press, Moscow and Leningrad, 1951), III, 249-259.

8. There had been a number of specialized laboratories in industrial plants in Russia before this time. They are descibed by P. M. Luk'yanov, "The First Chemical Laboratories in Russia," *Chymia 9,* 59-69 (1964). The construction and work of Lomonosov's laboratory is treated in N. M. Raskin, *Khimicheskaya Laboratoriya M. V. Lomonosova* (Academy of Sciences Press, Moscow and Leningrad, 1962).

number of mosaics, of which the most notable was his "Battle of Poltava," showing the victory of Peter the Great over Charles XII of Sweden.[9]

After 1750 Lomonosov's activities grew more and more varied. His work in the field of physics and metallurgy increased, and he began important studies in geography, mineralogy, astronomy, and meteorology. He taught a course in physical chemistry at the Academy in 1752 and was very active in the establishment in 1756 of the University of Moscow, the first university in Russia—the university which was supposed to have been part of the Academy of Sciences having never operated successfully. His literary activities increased steadily. He composed poetry all his life, but in his later years he also occupied himself with writing books on the history of Russia and on Russian grammar. He was influential in establishing the literary form of modern Russian.

During all this time his quarrels with other academicians increased. This was especially true for Schumacher, and later for the latter's son-in-law, I. K. Taubert, who succeeded to the directorship of the chancellery when Schumacher died in 1761. Much of Lomonosov's time in his later years was taken up with bitter recriminations against his scientific and literary opponents. Thus, although he was constantly planning to prepare enormous treatises on various phases of science in which he would explain his whole system in the various fields of knowledge, he was never able to complete more than the introductory sections of each. Many of his experimental and theoretical studies never went beyond the walls of the Academy, and were buried in the archives of that institution. Therefore most of his genius remained unappreciated, though his earlier works, which included much of his corpuscular theory, received more general recognition in his day. The extent of his influence is discussed in Chapter 4.

The last years of Lomonosov's life were not happy ones. He was plagued with debts from the factory at Ust Ruditsky and by almost constant ill health. His quarrels with his colleagues became ever more bitter. During his final illness he gave way

9. Lomonosov's work with pigments and mosaics is described by H. M. Leicester, *Journal of Chemical Education 46,* 295-298 (1969).

to pessimism, saying: "I see that I must die and I look on death peacefully and indifferently. I regret only that I was unable to bring to completion everything I undertook for the benefit of my country, for the increase of learning, and for the greater glory of the Academy, and that now, at the end of my life, I realize that all my good intentions will vanish with me."[10] He died on April 4, 1765.

A large part of his work did remain obscure until B. N. Menshutkin in 1903 began to unearth it. Menshutkin devoted much of his life to the recovery of Lomonosov's writings.[11] As a result, Lomonosov's prestige in the U.S.S.R. has risen steadily, and there is a great volume of Soviet literature devoted to all phases of his activities. To him the Russian historians of science attribute the foundation of Russian science. In Leningrad they have established the Lomonosov Museum in which are assembled the various instruments which Lomonosov made, and most of the other items relating to him which have been preserved.

2. THE SOURCES OF LOMONOSOV'S IDEAS

There can be no doubt that the philosophical basis of Lomonosov's approach to science was strongly influenced by the teaching he received from Christian Wolff at Marburg. Wolff was generally considered in his day to be the chief expositor of the philosophy of G. W. Leibniz (1646-1716), whose philosophical works he systematized and published.[1] The philosophy of Leibniz was essentially metaphysical. It underwent marked changes as it passed through the hands of Wolff, and Lomonosov still further adapted it to his own ideas. Lomonosov's mind was essentially practical, and he preferred physical models to metaphysical speculation. Nevertheless, certain of Leibniz's ideas can be recognized in the writings of Lomonosov.

Both Wolff and Lomonosov constantly stressed the two

10. Menshutkin, *Russia's Lomonosov,* p. 191.

11. See the evaluation of Menshutkin's work by Tenney L. Davis, *Journal of Chemical Education 15,* 203–209 (1938).

1. H. W. Carr, *Leibniz* (Boston, 1929; Dover, New York, 1960), p. 186; subsequent page references are to the Dover edition.

Leibnizian principles of contradiction and sufficient reason. These were expressed by Wolff in his early work on logic, *Vernünfftige Gedanken von den Kräften des menschlichen Verstandes und ihrem richtigen Gebrauche in Erkäntniss der Wahreheit,* first published in 1713, in the following way:

> I. Philosophy is the science of all possible things, together with the manner and reason of their possibility.
>
> II. By Science I understand, that habit of the understanding whereby, in a manner not to be refuted, we establish our assertions on irrefragable grounds or principles. What grounds are irrefragable, and what manner is irrefutable, will appear in the course of the following treatise.
>
> III. I call possible, whatever thing can be, or whatever implies no contradiction, whether actually existing or not.
>
> IV. As of nothing we can form no conception, so neither can we of the actual existence of any thing, without a sufficient ground or Reason; which shows why it rather is than is not; as will appear in its proper place. For the present let it suffice that the assertion is grounded in experience.
>
> V. A philosopher ought therefore, not only to know the possibility of a thing, but also assign the reason of that possibility.[2]

These ideas appealed greatly to Lomonosov, and he used them constantly throughout his works. He often sought to disprove a theory by showing that its rigorous application led to directly contrary conclusions, and he frequently referred to the principle of sufficient reason in his arguments.

Leibniz, a mathematician of the first rank, tended toward the abstract in his thinking. He interpreted the world in mathematical and metaphysical terms. He thought of mathematics as a science in itself, while Wolff, equally convinced of the importance of this discipline, felt that it should be applied in other sciences, at least as a method of treatment.[3] Lomonosov

2. The selection is taken from the English translation: *Logic or Rational Thoughts on the Powers of the Human Understanding with their use and application in the Knowledge and Search of Truth,* translated from the German of Baron Wolfius (London, 1770), p. 1.

3. W. H. Barber, *Leibniz in France; from Arnauld to Voltaire: A Study in French Reactions to Leibnizianism, 1670-1760* (Oxford, Clarendon Press, 1955), p. 124.

was also convinced that some form of mathematics should be used in explaining the nature of the world. In many cases he introduced algebraic or geometric proofs into his papers, and he obviously felt that these strengthened his case. It should be noted that his mathematics was of a rather elementary kind. He was not a mathematically minded scientist; in place of the abstract thinking of a Leibniz, he preferred concrete pictures and mechanical models to aid him in his speculations, and he was fond of reasoning by analogy from such models.

One of the chief features of the Leibnizian philosophy was his concept of monads. Atomistic ideas were in the scientific air at this time, as will be noted later, but most of these concerned atoms as physical realities. The Leibniz monads had little in common with these except that they were indestructible and were the units of the world. However, they had neither shape nor extension and were in a sense force units rather than units of matter.[4] Nevertheless, in building the universe they functioned in perfect harmony, since they had been created originally by God and subsequently worked only in accord with their own nature. Thus the world existed because of the pre-existent harmony among the monads.[5]

Probably the first exposure of Lomonosov to the concept of atomism came in terms of monads as interpreted by Wolff, but he must very soon have learned of the corpuscular philosophy of men such as Boyle and Newton. Their ideas of physical atoms and of the world as a "great mechanical clock" fitted better into the thinking of Lomonosov, but there was enough similarity to the metaphysical ideas of Leibniz so that the transition from a purely philosophical approach to the world to a mechanical one was not too difficult. It is perhaps significant that in his earliest papers Lomonosov spoke of his unit particles as "physical monads," but later abandoned this term and spoke of "elements."[6]

A further characteristic of some of Lomonosov's writings may have also stemmed indirectly from Leibniz. This was his evident aversion to Newton. Although he spoke of the "cele-

4. Carr, *Leibniz,* pp. 83-96.

5. *Ibid.,* pp. 103-108.

6. N. A. Figurovskii in *M. V. Lomonosov Izbrannye Trudy po Khimii i Fizike,* ed. A. V. Topchiev (Academy of Sciences Press, Moscow, 1961), p. 374.

brated" Newton on a number of occasions, it was usually to criticize some of his conclusions or to attempt to refute some of his statements. One has only to read his papers to note this apparent antipathy to Newton, which may have had its origin in the well-known polemic on the discovery of the calculus. It may also have had something to do with Lomonosov's antipathy for Boyle. Boyle and Newton were associated in men's minds at that time.

A direct example of the influence of Wolff on Lomonosov may also be cited. In his *Discursus praeliminaris de philosophia in genera,* published in 1728, Wolff drew up an elaborate classification of human knowledge, dividing it into three major classes: history, by which he meant factual information; philosophy, one of whose branches was physics; and mathematics, which dealt with the quantity of things. Physics was further subdivided into general physics, cosmology, meterology, oryctology (the science of minerals), phytology, physiology, and teleology. It is noteworthy that there is no room for chemistry as such in Wolff's classification.[7] Wolff believed that the true scientist should possess historical, philosophical, and mathematical knowledge of anything he studied.

These ideas are clearly reflected in one of the first works Lomonosov wrote after he returned to St. Petersburg, the "Elements of Mathematical Chemistry," a thoroughly Wolffian document. Since Wolff had not included chemistry in his classification, Lomonosov apparently decided to show that it too could be fitted into the definition of a science. He began the work in 1741, and though he did not complete it, he finished enough to show that chemistry could be treated in mathematical format from the standpoint of mechanics. His definition, "chemistry is the science of changes occurring in mixed bodies insofar as they are mixed," closely resembles Wolff's "philosophy is the science of the possibles insofar as they can be." His distinction between the historical (or factual) and philosophical (or theoretical) knowledge of chemistry is taken directly from the definitions of Wolff, and his introduction of the principle of sufficient reason in developing his ideas also comes from

7. *Preliminary Discourse on Philosophy in General by Christian Wolff,* trans. Richard J. Blackwall (Bobbs-Merrill, Indianapolis and New York, 1963), pp. 3-19.

that philosopher. However, his conclusion that "a true chemist should be theoretical and practical" and should be an adept in mathematics is his own synthesis. To be such a chemist, Lomonosov felt that the scientist must rely on mechanics. This view forms the basis of many ideas which he later worked out in more detail.

It is a matter of some interest and a further indication of the influence of Wolff that Lomonosov also drew to some extent at a later time on the final chapter of Wolff's *Preliminary Discourse.* This chapter was entitled "The Freedom to Philosophize,"[8] and is a defense of free speech for scientists. It was undoubtedly inspired by the fact that Wolff had been expelled from his teaching position at Halle in 1723 because of alleged teaching of atheism. Although he was later recalled to Halle, his feelings while in exile at Marburg were certainly strong, and this chapter reflected his personal distress. When Lomonosov in 1754 felt strongly the criticisms of his theories which had been published in certain German journals, he wrote a violent rebuttal which he entitled "The Duties of Journalists in the Accounts which They Give of Works Intended to Maintain the Freedom of Philosophers." Though the attack on freedom was not here as severe as in the case of Wolff, Lomonosov felt that unqualified critics should not be allowed to review the works of reputable scientists which represented their freedom to philosophize. It is perhaps significant that his article was published by J. H. S. Formey (1711-1797) in the journal *Nouvelle Bibliothèque Germanique* which he edited, since Formey was one of the chief disciples of Christian Wolff.[9]

On the basis of the philosophical teachings of Wolff and his own tendency to use the principles of macromechanics in forming a picture of the action of minute particles of matter, it was inevitable that Lomonosov should become an adherent of the mechanical or corpuscular theory of matter which had been prominent in the seventeenth century.[10]

8. *Ibid.,* pp. 88-120.

9. Barber, *Leibniz in France,* pp. 131-135.

10. The Democritean atomic theory had never completely died out, though owing to the influence of Aristotle it was in eclipse through most of the pre-Renaissance period. A useful chronology of the continued existence of atomic ideas is given by L. L. Whyte, *Essay on Atomism from Democritus to 1960*

Introduction

In *Il Saggiatore,* Galileo (1564-1642) expressed the idea that the properties of matter could be explained in terms of size, shape, and motion of the particles of matter.[11] All later mechanical philosophies, no matter how varied in detail, continued to insist on the primary importance of these properties, especially of motion. Gassendi (1592-1665) was most influential in reviving the old Democritean-Epicurean atomic theory which stressed the existence of individual atoms, separated by a void, which by their size, shape, and motion gave the properties of the visible world. However, he added that chemical properties were due to association of the atoms into molecules. Descartes (1596-1650), while denying the existence of atoms and the void, assumed that matter was particulate and divided into three categories. The third form consisted of large, differently shaped particles which as a result of friction from their slow motion had worn away, giving rise to smaller particles of a second matter (the ether), rapidly moving and also subject to abrasion, which gave rise to the first matter whose very small particles filled all the remaining space. Thus Descartes denied the occurrence of action at a distance, since there was always contact between the various particles. Distant action was generally denied by scientists of the time. Descartes also believed that heat and cold were due simply to the acceleration and deceleration of the movement of the material particles, and he explained solidity and fluidity by similar mechanical analogies.

Gassendi and Descartes presented their corpuscular theories as parts of their systems of general philosophy. These ideas were brought to the level of scientific theories chiefly by Robert Boyle (1626-1691). His corpuscular theory formed the basis on which Lomonosov erected his system. Boyle accepted the fundamental idea that motion, size, and shape of corpuscles were responsible for most of their properties. Like Gassendi,

(Harper Torchbooks, The Science Library, New York, 1963), pp. 40-84. A general account of the revival of atomism is given by A. G. Van Melsen, *From Atomos to Atom* (Harper Torchbooks, The Science Library, New York, 1960). A specific account of the rise of the mechanical philosophy and the ideas of Boyle and Newton is found in Marie Boas, *Osiris 10,* 412-541 (1952). For Boyle's debt to Gassendi, see Robert Kargon, *Isis 55,* 184-192 (1964).

11. Stillman Drake, *Discoveries and Opinions of Galileo* (Doubleday Anchor Books, New York, 1967), p. 274.

he recognized that these alone could not account for chemical properties, and so he believed that the simplest particles, his elements, were combined into larger aggregates. According to his well-known definition, the elements are the ultimate particles which are not themselves separable, but which can combine to form relatively simple substances that remain unchanged through a whole series of reactions. Gold is such a combination of elementary particles, and it can combine with similar simple aggregates to form mixed bodies of a higher order of combination. The simple aggregates are the corpuscles of which substances are composed, and their interactions and behavior produce the physical and chemical properties of the mixed bodies.

Isaac Newton (1642-1727), well acquainted with the corpuscular theory of Boyle, accepted most of its essentials, but in his theory of gravity he adopted the idea of action at a distance, and a number of later chemists assumed a force similar to that of gravity to explain chemical affinity. Lomonosov, who knew the work of Boyle and Newton well, utilized these ideas extensively, though, as stated earlier, he usually mentioned these scientists only to criticize some of their ideas. In the definitions given in the "Elements of Mathematical Chemistry" for elements, corpuscles, principles, and mixed bodies, we see essentially the same ideas as those of Boyle. They were to some extent superior to Boyle's, since the latter did not conceive of the existence of aggregates of homogeneous particles[12] while Lomonosov did. Lomonosov, like Boyle, thought of the atom as a physical rather than a chemical particle. It was not until the work of Dalton that the latter concept appeared.[13] Lomonosov's most original contributions came when he developed these ideas into his own theories.

While Boyle was primarily a chemist, he had made studies in his earlier work of the pressure-volume relation in gases and had stated the law now known by his name. However, he did not attempt to give a physical model to explain his results. The first attempt to present such a physical model, and to deduce from it mathematically the behavior of gases, was made

12. Boas, *Osiris 10,* 498 (1952).
13. A. W. Thackray, *Isis 57,* 36-37 (1966).

by Daniel Bernoulli (1700-1782) in his *Hydrodynamica,* published at Basel in 1738. Bernoulli, like his great friend Euler, had been an early member of the Academy in St. Petersburg, which he had left in 1733, and his work was well known and appreciated in Russia. In his kinetic theory, he assumed that the pressure of a gas was due to innumerable minute particles in constant motion which produced the pressure by striking the walls of the containing vessel. He showed that by this theory a mathematical statement of Boyle's law could be obtained, and he recognized that temperature increase would increase the rate of motion of the particles and thus affect the pressure. He also attempted to determine the effect of the size of the particles on the pressure at very high compressions. These ideas must have influenced Lomonosov greatly, for his picture of the elasticity of gases was practically the same. He cited Bernoulli directly in his paper in which he tried to find deviations from Boyle's law at high pressures.

Lomonosov was chiefly interested in the mechanism of material change and interpreted the behavior of matter almost entirely by macromechanical analogies. Therefore he was interested from his earliest studies in theoretical chemistry, or, in the terminology of his teacher Wolff, philosophical chemistry. Even when he was investigating a purely chemical reaction, he thought of it as a mechanical process. There was a practical chemistry (the historical part in Wolff's terms), and Lomonosov himself actively carried on intensive laboratory studies of glass and mosaics. However, he felt that the theoretical, or philosophical, side of chemistry required a rigorous treatment if chemistry were to become a true science. Accordingly, when he gave his course in chemistry in 1752, he "ventured to call this work physical chemistry . . . to bring together in it only what is contributed by a scientific explanation of mixed bodies." He added, "no one can deny that however little we have succeeded in explaining chemical phenomena by the methods of physics, we should properly use these methods with the same right as does physics itself."

In carrying out these ideas in his course, he also devoted much attention to what we now call the physical properties of the substances he was describing. Thus in two senses he was using the term "physical chemistry" in a systematic and charac-

teristic way. As Figurovskii has pointed out,[14] the expression had been used previously, at least as early 1716 by Kunckel and probably by others. However, they did not apply it on the logical basis which led to Lomonosov's choice of the phrase. Therefore Soviet historians of science have called him the first physical chemist. It would be well to recognize, however, that, as Lomonosov himself said, the term to him meant the same thing as "chemical philosophy," that is, theoretical as opposed to practical chemistry and not what the modern chemist means by this expression.

The course entitled "Introduction to the True Physical Chemistry" was given in the years from 1752 to 1754 and was even more an attempt to show that chemistry is a true science than was his earlier "Elements of Mathematical Chemistry." The two courses are given consecutively in the translations here to show how his ideas changed between 1741 and 1752. Much of the later course is descriptive of the methods to be employed in studying the physical properties of bodies, and the short fragment quoted at the end shows how carefully Lomonosov thought laboratory studies should be carried out. In this course Lomonosov called his elements "principles," and he found in their "cohesion" an explanation of many physical properties.

It can be seen that Lomonosov drew heavily on the physical science of the philosophers and physicists who preceded him. The application of their theories led him to many original ideas. His chemical views were more conventional, but they comprised an essential part of his thinking. He was well acquainted with the writings of the more chemically minded scientists of his period, and these men usually regarded the physical world from a somewhat different viewpoint than did the "natural philosophers." The two leading schools of chemical thought in the early eighteenth century were those stemming from the schools of Stahl (1660-1734) and Boerhaave (1668-1748).[15]

14. Earlier and contemporary uses of this term are discussed by Figurovskii, *Izbrannye Trudy*, pp. 468-469.

15. Maurice Crosland in *Studies on Voltaire and the Eighteenth Century* (Transactions of the First International Congress on the Enlightenment, Geneva 1963), pp. 393-400.

Stahl accepted some of the corpuscular ideas, speaking of atoms which could combine to simple, stable "mixts" which in turn could form larger complexes.[16] These ideas resembled those of Boyle, and probably reinforced Lomonosov's confidence in his own version of the corpuscular theory. However, Stahl was interested almost entirely in chemical properties and so did not even consider changes in weight when metals were calcined. The chemical behavior could be explained by assuming a loss of the fire principle, phlogiston, and this was all that mattered. Since phlogiston was a principle which could not be isolated and could be known only by its effects, Stahl confined himself to the subject which interested him, the chemical changes in combustion, and only incidentally considered physical properties. Boerhaave had a more theoretical approach to chemistry, but he did not believe that air could take part in a chemical reaction, a belief shared by Lomonosov. He believed with Boyle that fire consisted of particles of fire material. Of course, Boyle, as part of his mechanical philosophy, thought that heat was due to rapid motion of the fire particles, since they were smaller than other particles and so could move faster.

Lomonosov drew on the ideas of all these men for his chemical and mechanical theories, accepting and rejecting portions of their thought as he wished. It is sometimes possible to judge the importance which Lomonosov attributed to the work of various scientists by noting the number of citations of their papers which he gives. He was not in the habit of citing the work of others very often, and so when he did cite them, he must have felt their work was important. He was most strongly impressed by Stahl and Boerhaave, if we may judge by the number of his references to them. He quoted Stahl directly seventeen times and Boerhaave seven in the papers included here, while no other chemist was mentioned more than three times, and most only once.

It has been noted that Wolff did not include chemistry among the sciences, but Lomonosov had been sent abroad especially to study this subject. Presumably he learned the basic principles from Duising at Marburg, but it was probably at

16. Hélène Metzger, *Newton, Stahl, Boerhaave et la doctrine chimique* (Alcan, Paris, 1930), pp. 121-124.

Freiberg that he gained most of his chemical ideas, since Henkel was an abler chemist than Duising, and Lomonosov respected his knowledge even though he did not like him personally. He referred to Henkel at times in his papers, but Duising was never mentioned.

Henkel was a firm believer in the phlogiston theory, as were almost all chemists of his day, accepting the fact that addition of phlogiston to base metals raised them to noble metals and that by this process formation of ores and metals was continually occurring in the earth. These ideas were common at the time, and Lomonosov accepted them completely. When he was concerned with chemical changes, he showed much less originality than he did in developing his mechanical models and thus the concept of phlogiston which he held was clearly derivative. It should be noted, however, that even in his use of this concept, he tended more to stress the effect of phlogiston on the physical properties of metals than on their chemical behavior.

Thus, the studies of philosophy, physics, and chemistry during his three years at Marburg and Freiberg formed the basis on which all of Lomonosov's later thinking rested. However, as he continued his work at St. Petersburg, he developed his own interpretations of these ideas. The continuous development can be followed in his successive papers.

3. THE CHEMISTRY AND CORPUSCULAR THEORY OF LOMONOSOV

The corpuscular or mechanical viewpoint was employed by Lomonosov in his scientific thinking perhaps more completely and more consistently than by any of its other adherents. He applied it to physics, physicochemistry, and pure chemistry. He disapproved of Boyle's idea of rapidly moving fire particles since he considered motion alone the cause of heat. He rejected Newtonian gravity as an occult quality and proposed his own theory of a corpuscular gravity material. He converted Descartes's theory of the three matters into his own peculiar but still corpuscular theory of light and color. Thus in following his papers in more or less chronological order, we see how consistently he applied the mechanical philosophy to whatever

phenomenon happened to attract his attention at a given time.

One of Lomonosov's earliest scientific papers, and certainly one of his most important, was the "Meditations on the Cause of Heat and Cold," for in this he first introduced his concept of the three types of motion—progressive, oscillatory, and rotary—by which he subsequently explained all material phenomena. That he himself considered it basic to his later work is shown by the fact that he cited it more often in the papers included in this book than he did any of his other papers. It has also been the paper best known to Western scientists, largely because B. N. Menshutkin in 1910 published excerpts from it in the series of Ostwald's *Klassiker*.[1]

Since Lomonosov was not concerned in this paper with chemical phenomena, he mentioned phlogiston only incidentally, and since he was developing a mechanical theory of heat, he denied the existence of a fire material, the caloric of later chemists. This has led to a belief among Western historians of science that Lomonosov did not believe in phlogiston. This idea was strengthened by the fact that even in his last biography of Lomonosov, published in 1937 (translated into English in 1952), Menshutkin, who had spent a lifetime in the study of Lomonosov, apparently still did not like to admit that his hero could believe in phlogiston. He therefore said that "in explaining chemical phenomena he [Lomonosov] makes use of the theory of phlogiston, probably in order to be more comprehensible to his hearers and readers who were undoubtedly acquainted with the basic chemical hypothesis of the time."[2]

Actually, as will be seen, Lomonosov believed fully in the reality of phlogiston and used the concept in explaining many facts, though he did use it more in relation to physical effects than to its action in combustion. This point has recently been stressed by Soviet historians of science.[3]

1. Wilhelm Ostwald, *Klassiker der exacten Wissenschaften,* no. 178 (W. Engelman, Leipzig, 1910).

2. B. N. Menshutkin, *Zhizneopisanei Mikhaila Vasil'evicha Lomonosova* (Academy of Sciences Press, Moscow and Leningrad, 1937), p. 187; English translation, *Russia's Lomonosov* (Princeton University Press, Princeton, N.J., 1952), p. 156.

3. See, for example, N. A. Figurovskii in *M. V. Lomonosov Izbrannye Trudy po Khimii i Fizike,* ed. A. V. Topchiev (Academy of Sciences Press, Moscow, 1961), pp. 410-420, and N. M. Raskin, *Khimicheskaya Laboratoriya M. V. Lomonosova* (Academy of Sciences Press, Moscow, 1962), pp. 100-101.

In his paper on the cause of heat and cold, Lomonosov proved by logical argument that heat consists in internal motion of the corpuscles of a material and, in fact, in internal rotary motion. It is rather characteristic that in many of Lomonosov's scientific papers he did not appeal directly to experiment, but rather to general experience and common knowledge, and from these he built up a theory. The fact that he did not obtain suitable laboratory facilities until 1748 probably accounts for this in part, but his own fondness for macromechanical analogies would also seem to have been a factor.

The picture which Lomonosov composed to explain his theory of the solid state was that of a mass of solid corpuscles cohering to one another in mutual contact. He did not believe in action at a distance, and so always had to have some sort of physical contact between particles. For greater ease of rotation about one another the particles should be spherical in shape. This became one of his most characteristic concepts. The previous mechanical theories had based the properties of matter on motion, size, and shape of the particles. Lomonosov retained motion and size, but reduced all shapes to spherical and applied geometric reasoning to show how physical and chemical properties could be explained on this assumption. He later developed the idea of spherical corpuscles in much greater detail, but he suggested it in his earliest papers. Between the corpuscles there were pores of various sizes which could be penetrated by smaller corpuscles. This idea was also greatly expanded in his later writings. Heat was due to rotary motion of the corpuscles, and was greater when rotation was rapid, less when rotation was slower.

This picture of the structure of matter made it possible to represent the action of the invisible corpuscles in terms of macromechanics, and Lomonosov offered a number of examples of model mechanisms. His kinetic viewpoint permitted him to deduce that there could be no upper limit to temperature, but that a lower limit must exist when complete cessation of movement of the corpuscles would occur. He thus foresaw the concept of absolute zero. Further consideration of his theory led him to reject completely the idea of a fire material which Boyle and Boerhaave had incorporated into their systems. He criticized Boyle's explanation of his experiments on making fire and flame stable and ponderable, pointing out that the increase

in weight of calcined metals might well be due to "particles flying around in the air, which flows continually around the calcining bodies" and that something could thus be added which would increase the weight.

In the original form of his paper on the cause of heat and cold which he read to the Academy of Sciences in January of 1745, he criticized Boyle's account of his experiments in very strong terms. Thus, referring to the experiments on burning copper plates with sulfur he said: "I am amazed that a scholar, cautious in other cases, has not here made sufficient study and does not remember the acid spirit which flame draws from sulfur and which, penetrating metals, causes swelling and increase weight by its combination."[4]

Such an attack on a world-famous figure by a young adjunct of the Academy of Sciences apparently alarmed the academicians, for the report of the session included the following statement:

> The purpose and industry of the Adjunct deserve commendation in the search concerning a theory of heat and cold, but it seems that he too hastily sets about a matter which appears to be beyond his strength; especially insufficient is his argument in which he tries in part to confirm, in part to refute the different internal motions of bodies, and this the Adjunct himself admits when he wishes only a demonstration of his special explanation, giving an account in the form of a syllogism. The opinion was also expressed that the Adjunct should not try to name the work of Boyle which is, however, treated with fame in the learned world, for he notes in his communication only such a place in which as it were he [Boyle] goes astray, and passes over in silence many other points where he shows examples of deep learning.[5]

Lomonosov did modify his criticism somewhat in the final published form of the paper, as shown in paragraph 31 of the

4. *M. V. Lomonosov Polnoe Sobranie Sochinenii* (Academy of Sciences Press, Moscow and Leningrad, 1951), II, 95-97.

5. Quoted in G. E. Pavlova, *M. V. Lomonosov v Vospominaniyakh i Kharakteristikakh Sovremennikov* (Academy of Sciences Press, Moscow and Leningrad, 1962), p. 104.

work (*see* p. 114), but he did not really change the sharpness of his attack. He continued to be interested in this problem, and in 1756 he reported to the Academy of Sciences: "In chemistry. 1) Among the various chemical experiments in this journal of 13 pages we made experiments in tightly sealed glass vessels so as to study whether the weight of the metals increased from pure fire; by these experiments it was found that the opinion of the famous Robert Boyle was false, for without entry of the external air, the weight of the burned metal remained at the same measure."[6]

This brief note indicates that in 1756 Lomonosov performed the same experiment which Lavoisier later carried out. In both cases the aim was to refute Boyle's theory of fire particles which could penetrate glass and increase the weight of a calcined metal. There is no doubt that this was Lomonosov's aim, but he never published these results and so they could not have affected Lavoisier later. He had stated in his paper on heat and cold, published in 1750, that the increase in weight of a calcined metal could come from "particles flying around in the air," and so his experiment of 1756 can be considered to be an attempt to check this experimentally. It has been so considered by Soviet historians of chemistry. However, Pomper[7] has pointed out that this was not the only explanation offered by Lomonosov. In a long letter to Euler in 1748, Lomonosov suggested that during calcination the surfaces of the metallic corpuscles might be more freely exposed to a gravitational fluid which he assumed gave weight to substances by striking their surfaces. In 1748 this could have been merely one of a number of hypotheses by which the phenomenon of change in weight was explained. However, in 1758, two years after performing the experiment described above, Lomonosov presented a paper on the relation of amount of material and its weight in which he printed in practically unchanged form the letter which he had sent to Euler ten years earlier. He included the section on gravitational fluid and weight. As Pomper says, the problem of Lomonosov's views on combustion must remain open until further evidence is obtained.

6. Raskin, *Khimicheskaya,* p. 147.
7. Philip Pomper, *Ambix 10,* 119-127 (1962).

At about the same time that he was writing on heat and cold, Lomonosov also developed his ideas on solution, which he regarded as a chemical phenomenon. To Lomonosov chemical usually meant what we would call physicochemical, and, indeed, as has been seen, he was the first to use this name in a systematic way. Thus, although his theories of solution were based on his mechanical viewpoint, he entitled his paper "On the Action of Chemical Solvents in General." In this paper he reported a number of relatively simple experiments which he had actually performed, and he attempted to give these a quantitative character. Here also for the first time he considered phlogiston seriously, ascribing the luster and ductility of metals to its presence in them. He distinguished two types of solution, that of metals in acids, which was accompanied by evolution of heat, and that of salts in water, which often occurred with cooling. In explaining the first, he showed the interest in the elasticity of air which he later developed in detail. He believed that air already in the pores of the solute lacked elasticity, but when the air in the pores of the solvent was added to it, the elasticity became so great that it tore off particles of the solute, and solution occurred. The heat came from the friction of the torn-off particles. The calculations which he used to support his theory did not involve any complex mathematical ideas, but they did show his lack of comprehension of significant figures. It is not often, in modern scientific papers at least, that a fraction such as 886,717,312/63,207,309,312 is encountered.

He thought that the pores of salts were already filled with water and so, when salts were placed in water, it was not air but water particles themselves which excited to faster rotary motion the salt particles, for conversion of a solid to a liquid resulted when rotary motion was increased (as in melting). Thus the now more rapidly rotating salt particles separated and scattered through the water. Here Lomonosov made use of another principle which he was later to emphasize, that if anything is given by a body to another, so much must be taken away from the donor. Since rotary motion of the salt particles was increased, rotary motion of the water particles must correspondingly be decreased, and so the water was cooled. Thus the physical effects of the two types of solution were explained.

Following these papers, which belong rather to the field of

physics, Lomonosov turned to purely chemical subjects. Here he showed himself less of an innovator, for he accepted the doctrine of phlogiston and quoted frequently from various chemical authorities. Nevertheless, he still introduced his mechanical theories and macromechanical models, and he showed that at all times he was more interested in the physical than the chemical properties of the substances concerning which he wrote.

In his paper entitled "The Luster of Metals," he developed in detail the idea which he had mentioned in his paper on solution, that the luster and ductility of metals were due to their phlogiston content. This was an idea which came from Stahl himself. Stahl conceived of phlogiston not as a material substance, but as the principle of combustibility, the "fatty earth" of Becher, which probably did not possess weight but could affect the properties of substances which contained it. One such property was color.[8]

This idea was expanded by Stahl's follower, J. H. Pott (1692-1777), who wrote in 1716:

> I maintain the most usual idea of the word sulfur, and I mean by sulfur of metals that fatty and so to speak shining earth which gives to metals their color and ductility, which is in part incombustible, and which has its place with the other earthy principles of metals and which alone is capable of receiving color or light. I willingly allow those who prefer the philosophy of Descartes to believe that this principle is composed of branching, flexible particles made with hooks or some other shape.
>
> The sulfur of metals, independently of all these opinions, differs in degree of purity and fixity. For example, in ordinary sulfur, because of the great quantity of undigested bituminous substance, our volatile principle is superabundant in it; it is more fixed and more digested in minerals; this degree of fixity and maturity increases in the imperfect metals and finally becomes as perfect as possible in gold and silver.[9]

8. J. H. White, *The History of the Phlogiston Theory* (Arnold, London, 1932), pp. 54-56.

9. J. H. Pott, *Dissertation on the Sulfur in Metals.* The work was first published in 1716 and was reprinted in *Dissertations chymiques de M. Pott* (Jean Thomas Herrisant, Paris, 1759). The citation was taken from this edition, I, 8-9.

Lomonosov was well aware of these ideas, since he quoted this work of Pott in his paper. However, the foregoing paragraphs form only a small and incidental part of Pott's book, which, like most of his writings, is of a practical nature. Lomonosov expanded the concept in a largely theoretical manner. Accepting the theory that when metals were converted into calxes and glasses by combustion they lost their phlogiston, he drew the conclusion that they would also lose their luster and ductility. The greater the phlogiston content and the more firmly it was held, the nobler would be the metal. Thus gold and silver, which by analogy with the baser metals also owed their luster and ductility to phlogiston, had to hold the latter more firmly, since they could not easily be converted to calxes. He was convinced that metals were continually being formed in the earth by gain of phlogiston from sulfur or arsenic (sulfur was a compound of vitriolic acid with phlogiston). When iron was treated with an acid, an inflammable vapor was given off "which is nothing else than phlogiston" (an anticipation of Cavendish, who also considered hydrogen to be phlogiston). He thought it should be possible to transmute metals by addition of phlogiston to them. Thus, Lomonosov's chemical theories were those common in his day which he had learned from Henkel, but he never stressed the role of phlogiston in combustion very heavily.

All the papers discussed up to this point were published in Latin in the journals of the St. Petersburg Academy of Sciences, which circulated generally among scientists of the time. The next paper to be considered was not so well known, since it was submitted to the Berlin Academy of Sciences in competition for a prize which Lomonosov did not win. Nevertheless it was read and approved by Euler and must also have been discussed when the award of the prize was being considered. Thus it was not as unavailable in the West as were many of Lomonosov's writings, which reached only the members of the St. Petersburg Academy who heard them read. The paper was "On the Origin and Nature of Niter," and it is the only one in which Lomonosov attempted a purely chemical discussion of the composition of a substance. It is well to consider it in the light of his basic theories and those of his time.

The production of potassium nitrate, then called saltpeter or niter, was of great importance in the eighteenth century because of its use in gunpowder. It was usually obtained by scraping the white efflorescence from walls of buildings located near piles of putrefying animal or vegetable materials, and so it was assumed that lime and "urinous salt" (ammoniacal compounds) were among its constituents. The production in the first half of the century was largely confined to Sweden and Germany.[10]

At the beginning of the century Stahl had recognized that niter was a salt, and he considered that the acid portion was vitriolic acid, the closest approach to the universal acid, but modified by the addition of phlogiston which came from the putrefying materials. This modified acid was the spirit of niter which combined with an alkali to give niter itself.[11] This theory was accepted until after the death of Lomonosov, when Abraham Granit in 1771 denied that nitric acid was a modification of sulfuric acid and also denied that volatile alkali (ammonia) or lime entered into the composition of niter. He emphasized the need for a strong circulation of air in the manufacturing process.[12] Thus the theory first proposed by Stahl dominated in 1748.

In that year the Berlin Academy of Sciences offered a prize for the best dissertation on the origin and nature of niter. At the suggestion of Euler, Lomonosov submitted a long paper on this subject, but his essay was passed over, and the prize was given to a certain Dr. Pietsch who, as his essay showed, was a practical chemist long associated with the manufacture of niter. It is of interest to compare the two essays, since the choice of the Academy well illustrates how contemporary chem-

10. By 1776 France realized how backward it was in such production, and a commission was appointed by the Paris Academy of Sciences to rectify the matter. The members of the commission were Macquer, d'Arcet, Lavoisier, Sage, and Baumé. They began their work by making a historical survey of theories of the composition of niter and practical methods of its production. This was published as *Recueil de mémoires et d'observations sur la formation et sur la fabrication du Salpêtre* (Chez Lacombe, Paris, 1776). This work contained translations of many papers on niter.

11. *Ibid.*, pp. 20-21.

12. *Ibid.*, pp. 403-456.

ists felt when they had to choose between a practical chemical approach and a highly theoretical paper utilizing speculative mechanical principles to explain chemical facts.[13]

Both authors assume the Stahl theory of spirit of niter as a modified sulfuric acid and its combination with a fixed alkali. Both are concerned with the attempt to determine the proportions of each constituent in niter, though neither is able to do more than speculate on these proportions. Both describe the actual methods for preparing niter. Beyond this, the two papers differ completely in essence. Pietsch is entirely practical. He uses experiments to verify all his statements. He assumes that the lime which he believes is required is used to form "crude niter" which is first formed on nitrifying walls, and then this crude niter reacts with fixed alkali (either spirit of tartar, potassium carbonate, to give "prismatic niter," or marine salt, to give cubic niter).[14] He supported this view by a number of experiments which, in view of the impurities in the materials he was using, are of high quality. Throughout his essay he appealed always to his own experiments, and he remarks at one point: "To wish to demonstrate in chemistry without experiments is to wish to construct a building without a foundation."[15]

In contrast, Lomonosov reported hardly any experiments, and when he did report any, they were not his own. Instead he began his essay with a general part explaining his basic principles of chemical combination in terms of a mechanical model of cog wheels interacting with one another. He went on to develop the theory of the nature of nitric acid in a way similar to but more detailed than that used by Pietsch, but his theory of the nature of the alkaline portion of niter was much more complicated. He assumed that the alkaline earth, which he also believed was an essential part of the alkali, was modified by the presence of some acid material and phlogiston. He

13. The Pietsch essay was published in Berlin in 1750 as a pamphlet in French. The full text is given in *Recueil de mémoires,* pp. 163-214.

14. Potassium and sodium nitrates were distinguished by their crystal forms. See M. P. Crosland, *Historical Studies in the Language of Chemistry* (Harvard University Press, Cambridge, Mass., 1962), p. 76.

15. *Recueil de mémoires,* p. 182.

used his corpuscular ideas even to explain the crystal form of niter. His description of the actual manufacture of niter was more detailed than that of Pietsch, and each step was explained on theoretical grounds. It is easy to see why the Berlin Academy gave the prize to Pietsch, for his paper was very clear and straightforward and its experimental approach must have been appealing, while the often involved explanations of Lomonosov and his use of mechanical analogies must have struck the members of the award jury as being too sophisticated. Nevertheless this essay, with its wide-ranging speculation and its often deep logic, shows how Lomonosov could accept the phlogiston theory and yet go beyond it into wholly new concepts of science.

The only other paper entirely on chemistry which Lomonosov prepared was his "Oration on the Use of Chemistry," and this was not a piece of original research. It was a formal oration prepared for the name day of the Empress Elizabeth, daughter of Peter the Great, and it is full of flattering allusions to her and of the poetic and rhetorical language which was expected at that time in a formal address. It does, however, reflect in some respects the expansion of Lomonosov's scientific interests. Thus, he now adds optics to the mechanics and mathematics which the chemist should know, and he shows interest in color, specifically mentioning colored glass and mosaics. Since at this time (1751) he was making his studies on the preparation of colored glasses for mosaic pictures, and was developing his own theory of color which he presented in 1754, these references are understandable. Of course, he did not fail to mention rotary motion as the cause of heat, for this was always on his mind. Of interest is his claim that the invention of gunpowder had mitigated the horrors of war. This was not the only time that the invention of a new weapon had been seen as a deterrent to war.

Beginning in 1748, Lomonosov became more and more interested in the physical consequences of his kinetic view of the behavior of corpuscles. His earlier papers had shown that he was interested in the elastic property of air, which, in common with his contemporaries, he regarded as a purely physical substance unable to enter into chemical reactions. Boyle had made some attempt to develop a kinetic theory of the elasticity

of air, but had not pursued it.[16] Bernoulli had attempted a mathematical treatment of this phenomenon. Lomonosov perceived most of the implications of such a theory. Pneumatic chemistry was beginning to develop at this time, but there is no indication that Lomonosov was in any way involved in this. Therefore he was justified from his point of view in assuming that "those particles of air which produce elasticity, tending to separate from each other, lack any complexity and organized structure," but being unable to undergo any changes, can safely be called "atoms" as distinct from corpuscles or mixed bodies which, like our molecules, have structures specific to them and can undergo changes, that is, chemical reactions. However, the atoms do cause heat in other bodies, that is, excite them to rotary motion, and so these atoms are probably spheres with roughened surfaces which can excite heat by friction. Since there is no action at a distance ("one body cannot act directly on another without contact with it"), but air can be strongly compressed, there must be spaces between the atoms, and these atoms must be moving randomly in this space and striking each other with a following rebound which drives them apart. Once again a macromechanical model supplied Lomonosov with an explanation for his theory. It was the rough surfaces of the rotating atoms which caused their mutual repulsion on contact, and the higher the temperature, that is, the faster their rotation, the greater would be the force of their rebound and the greater the elasticity of the air. As usual, Lomonosov then proceeded to explain a number of other observations as a result of his kinetic theory, in general quite correctly.

When Lomonosov read this paper before the Academy of Sciences, his colleague Richmann pointed out that this theory did not explain the relation between the elasticity of air and its density. Lomonosov was not sure that the relation expressed by Boyle's law was entirely correct, and so he devoted a year to an experimental attempt to test it. Unfortunately, he based his experiments on the false premise that the expansion of ice when water froze was due to liberation of air from the pores of the water at the moment of freezing, and that this accounted for the expansion which could break the vessel in which the

16. Marie Boas, *Osiris 10,* 476-477 (1952).

freezing occurred. He therefore believed that he could measure the elasticity of air by measuring the force required to break the vessel. Thus his experiments and the calculations which he based on them were without significance. However, he did conclude from his mechanical model that when the air is greatly compressed, its density is not proportional to its elasticity. Thus he gave a model to show the effect of particle size on compressibility, a fact which had been suggested by the mathematics of Bernoulli. He presented this work as a supplement to his paper on elasticity of air in 1749, and the two papers were published in the same volume of the *Novi Commentarii Academiae scientiarum imperialis Petropolitanae* in 1750.

In the same period, 1747-48, Lomonosov considered the problems connected with density and weight of solids. He took issue with Newton's view that the quantity of a body is proportional to its density, at least in the case of heterogeneous substances. He argued that gold and water particles must be of the same shape and because of the incompressibility of these substances their general structure could not be different. Therefore he tried to explain their differences through a theory of gravity. He denied that gravity could be explained by a pure attractive power innate in material bodies, since in his view this would imply an occult quality, and his mechanical bias made him reject this and consider that Newton, or at least his followers, had restored this occult quality to scientific respectability. The cohesion of particles, then, if not due to innate attraction, had to be due to an external blow. Here he presented his theory of the conservation of matter and motion: as much of either of these as is added at any point must be taken away at another.[17] His argument led him to the view that there is a gravitational material, an extremely subtle fluid, which acts when its particles strike the surfaces of corpuscles where these particles cannot penetrate the pores between the corpuscles. Corpuscles of different sizes will be affected differently; those with larger surfaces will be struck by more gravity particles and hence will be heavier. Thus, by introducing a mechanical theory of gravity, Lomonosov felt that he had done

17. See note 7 above. Pomper has pointed out the overemphasis by many Soviet historians of science on this aspect of Lomonosov's thought.

away with Newton's occult quality. In this discussion Lomonosov again repeated his idea that fire is not fixed in calcined bodies, but their increase in weight is due to combination with particles from the surrounding air or else to a change in the amount of surface exposed to the gravitational particles.

These ideas were developed in 1747 and expressed in a long letter which Lomonosov sent to Euler on July 5, 1748. They were not put in the form of a scientific paper until 1758 when he read them in essentially the same words as in his letter at a session of the Academy of Sciences. Even so, this paper was not published, but was deposited in the archives of the academy. Thus it could not have been generally known, except to a small circle of friends to whom Euler might have mentioned it.

Lomonosov's last important paper on the corpuscular theory was presented in August of 1760 and was inspired by the successful freezing of mercury which Braun and Lomonosov had carried out the previous winter. This led Lomonosov to review his corpuscular ideas on the nature of cohesion and the structure of liquids and solids. The paper, "Meditations on the Solidity and Liquidity of Bodies," began by repeating the arguments which had been used in the paper on density and weight against the existence of an innate attractive force in bodies. Since the latter paper had not been published, Lomonosov probably welcomed the opportunity to express these ideas again, especially since he knew that the freezing of mercury had been widely acclaimed in western Europe, and so a paper dealing with this subject would probably be read extensively. He then went on to show mathematically that the spherical form was the only one in which material particles could exist, and in his only major attempt to account for affinity, a leading problem for most eighteenth-century chemists, he showed by a mechanical model how spheres, in actual contact at one point only, could have a surface of cohesion. This was greater for larger spheres, and thus bodies with larger corpuscles would show greater cohesion, having higher melting points and differing in other properties that depended on cohesive forces. He then described in some detail the actual experiments on freezing of mercury. There had always been some question as to the metallic nature of this substance, and so great interest

was aroused when the Russian academicians showed that in solid form it closely resembled the other metals. This portion of Lomonosov's paper was therefore the most widely discussed. It received considerable attention even in the *Philosophical Transactions* in England.[18]

After Lomonosov occupied his new chemical laboratory in 1748, he began to devote more and more time to experiments on the manufacture of colored glasses for his mosaics. This work led him to speculate on the nature of light and color, and he found that he could fit these phenomena into his corpuscular system. He presented his theories on this subject in a formal oration which he presented to the Academy of Sciences in 1756. Although once again his language was, of necessity, rhetorical, he took the occasion to expound his new theories in detail, and so this oration has more of the character of a scientific paper than was the case with his oration on the use of chemistry.

Descartes had attempted to develop a mechanical theory of light and color, and his ideas obviously served as a basis for those of Lomonosov, but the latter could not agree with the direction taken by Newton.[19] In particular he objected to what he called Newton's "streaming theory of light." He retained the idea of corpuscles, as he had to do to keep his mechanical philosophy, but he combined his own version with many elements of Cartesian theory to produce a very original theory of the nature of light, and especially of color. A striking feature of his color theory was his recognition of the three primary colors, red, yellow, and blue. His predecessors had never been able to agree on the number of primary colors, and here Lomonosov showed his originality.[20] The remainder of his theory is more notable for the ingenuity of the manner in which he combined the three-element theory of Paracelsus with physics and optics than it is for its accuracy.

18. *Philosophical Transactions 51,* pt. 2, 670-676 (1761).

19. For the Cartesian and Newtonian systems, see R. S. Westfall, *Isis 53,* 339-358 (1962).

20. Mariotte had earlier proposed these three colors as primary, but he had added black and white to them. The relation of the theories of Mariotte and Lomonosov is discussed by K. S. Lyalikov in *Lomonosov Sbornik Statei i Materialov* (Academy of Sciences Press, Moscow and Leningrad, 1951), III, 17-32.

He began the paper with a severe criticism of Newton's corpuscular theory, the theory of a flowing motion of light as he called it. He accepted the fact that light is due to the motion of the ether, a very subtle and elastic fluid "which no one now doubts." This was his first extensive use of the concept of the ether. The idea of imponderable fluids, which stemmed from the second matter of Descartes, was gaining ground at this time and by the end of the century was being used by most scientists to explain the nature of such phenomena as heat and electricity. These were not generally conceived as being particulate. Lomonosov also used the concept of very subtle fluids, as in his theory of gravitational matter, or of ether in his optical theories, but to him these fluids were strictly corpuscular, and their properties could always be explained by mechanical analogies.

The types of motion available to the ether particles would be the same as those available to the corpuscles of matter. Therefore Lomonosov considered the motions of light in some detail. He devoted much attention to a disproof on mechanical grounds of the flowing theory of light. If such motion was impossible, light could not have a progressive motion. Light and heat exist separately, for there can be light without heat, as in the rays from the moon. Heat, as he constantly stressed, is due to rotational motion of material corpuscles. The ether particles coming from the sun can also have rotational motion. Such rotational motion of the ether particles can excite rotational motion in material bodies, heating them. Thus light cannot be due to rotational motion of the ether particles. Therefore only the third type of motion remains for it. "Since the ether cannot have a flowing motion, and the rotary motion is the cause of heat without light, there remains only the third, an oscillatory motion of the ether which should be the cause of light." Having thus shown on theoretical grounds that light is due to an oscillatory motion, Lomonosov went on to prove this by comparison with sound waves in air. When the rotary motion of the ether produced heat in material bodies, its own rotary motion was blunted and only oscillatory motion was left. Hence there could be light without heat.

Lomonosov then turned to his rather complicated theory of the nature of color. For this he presented a theory of the

structure of ether which was essentially identical with Descarte's theory concerning the three forms of matter, though he did not mention Descartes in this connection. He assumed ether particles of three sizes, one type relatively large, the second smaller, the third very small. He compared them to cannon balls, bullets, and small shot, and pointed out that a mixture of these would leave no free space and would everywhere have the same composition, properties characteristic of the ether. He then extended the idea he had previously presented several times, that interaction between spherical particles could occur only if the roughness of their surfaces could intermesh, as in cog wheels. If such intermeshing could occur, he called the particles compatible; if it could not, they were incompatible. He now had three types of ether particles and three primary colors. He needed three material bodies to be acted upon. He turned to chemical theory and stated that most chemists accepted chief and subsidiary materials in bodies. The chief materials were the three elements of Paracelsus, salt (or acid), mercury, and sulfur. The subsidiary ones were watery and earthy particles. He was now ready to combine all these theories. For each type of ether corpuscle there was a compatible type of primary material, and for the excitation of rotary motion in each type of primary material there was a corresponding color produced when that type of material was stimulated in the eye. The optic nerve then carried the sensation to the brain by successive stimulation of the compatible particles along the nerve much as a series of intermeshing cog wheels will turn when the end wheel is turned. The largest type of ether particles was compatible with acid corpuscles in the material body and when these turned, the sensation of red was produced. The second type interacted with mercury and produced yellow. The third type reacted with sulfur, the inflammable principle, and produced blue. Other colors resulted from mixture of the primary colors.

On this theoretical basis the colors of material substances could be explained. If the surface of a substance were covered by all three types of particles, the rotary motion of all three types of ether particles would be blunted, none could reach the optic nerve, and no sense of color resulted. Hence the object was black. If the surface were covered by the secondary

types of matter, watery or earthy, there was no blunting of the ether particles, all colors were reflected and reached the eye, and the object appeared white (this much of Newton's demonstration Lomonosov accepted). If the surface were covered mostly with acid material, the rotary motion of the large ether particles was blunted, the other two types (producing blue and yellow sensations) reached the eye, and green resulted. If two types of material were on the surface, only the primary color corresponding to the third would be observed. Lomonosov was careful to point out that while rotary motion was responsible for both heat and color, it was rotary motion of material particles which was responsible for heat, while it was rotary motion of the ether particles which produced color. He illustrated the consequences of this theory by numerous examples.

To be completely consistent in his corpuscular theory, Lomonosov felt that he should be able to explain electricity also in corpuscular terms. He developed a theory of the origin of atmospheric electricity and lightning in terms of the upward and downward motion of columns of warm or cold air, recognizing the importance of friction in producing electrical phenomena. This was obvious, for the static machine was used to demonstrate electrical effects in his day. Since electricity, like light and heat, could cross an airless space, he felt it should be explained like light and heat as a form of motion of the ether. In 1756 he began to prepare a paper on "Theoria electricitatis methodo mathematica concinnata," reverting to the mathematical format he had used in the "Elements of Mathematical Chemistry."[21] His proposed table of contents was very comprehensive. He began with a discussion of the properties of insulators and conductors. He then showed logically that electricity was due to the motion of the ether. He proceeded to a discussion of motions of the ether particles which produced heat and light (rotary and oscillatory), repeating most of the arguments he had used in his oration on light and color. At this point he broke off and so came to no theory of the

21. The paper is given in *M. V. Lomonosov Polnoe Sobranie Sochinenii* (Academy of Sciences Press, Moscow and Leningrad, 1952), III, 265-313, and in *Izbrannye Trudy*, pp. 273-293.

nature of electricity. The editor of the *Izbrannye Trudy*[22] suggests that he may have found it too difficult to incorporate electricity into his theory, and this seems likely, since he had already used up all forms of motion of the particles which his theory allowed, leaving none for electricity. At any rate, he was never able to extend his corpuscular theory any further than he had carried it in his oration on light and color.

Although Lomonosov was the professor of chemistry in the Academy of Sciences, and considered "chemistry my chief profession,"[23] his theoretical ideas were essentially those of a physicist. Marie Boas has pointed out the reather clear-cut distinction between the believers in chemical and physical atomism in the eighteenth century.[24] Lomonosov certainly belonged to the latter group. However, since he had said that the true chemist must be both theoretical and practical, it should not be forgotten that he had a great interest in the practical applications of chemistry. He was well acquainted with the technology of niter production, as his paper on the composition of niter shows, and in his oration on the uses of chemistry he pointed out the many applications of this science for the benefit of mankind. He contributed greatly to the mineralogy of Russia, and his work on glass manufacture for use in mosaics was of significant value.

It can be seen from this summary of the theoretical papers on corpuscular theory that Lomonosov held consistently to his mechanical philosophy over his entire active scientific career from about 1741 to 1760. Many of the ideas which were suggested in his earlier papers were later developed in full detail, and many profound insights, well ahead of those of his contemporaries, were evolved by the Russian polymath. At the same time, the relatively small number of experiments which he performed and the reliance which he showed upon reasoning by analogy often led him into too facile flights of theorizing. Although he could suggest crucial experiments, he seldom had time to carry them out, or when he did, the results were

22. P. 535.

23. Lyalikov, *Sbornik Statei,* p. 17.

24. "Structure of Matter and Chemical Theory in the Seventeenth and Eighteenth Centuries" in *Critical Problems in the History of Science,* ed. Marshall Clagett (University of Wisconsin Press, Madison, Wis., 1951), pp. 499-514.

not published. His extremely varied activities, his constant quarrels with his opponents in and out of the Academy, and his time-consuming activities in developing his mosaic industry when he did enter the laboratory all prevented that close contact with "historical" chemistry which he had declared in his "Elements of Mathematical Chemistry" to be essential for a true chemist. While we must applaud his remarkable abilities as a scientist, we must regret that he did not devote more time to his scientific work.

4. THE SIGNIFICANCE OF LOMONOSOV'S CORPUSCULAR THEORY IN THE HISTORY OF SCIENCE

It is a well-known fact that much of Lomonosov's scientific work was never published and was only discovered after Menshutkin in 1903 began his investigations of the papers deposited in the archives of the Academy of Sciences. In fact, so little was Lomonosov's scientific work recognized outside of Russia in the century following his death that when Ferdinand Hoefer wrote his history of chemistry in 1869, he could mention "Lomonosov the chemist, who is not to be confused with the poet of the same name."[1]

In the years following his death, Lomonosov was known even in Russia chiefly for his poetry and his historical and philological works. This may well have been because of his activity in founding the University of Moscow in 1756 which made him well known to the faculty of that university, but they were well acquainted only with his nonscientific works. Hence, after his death, these men enthusiastically praised only his literary writings, ignoring Lomonosov the scientist.[2]

His scientific theories were not completely forgotten by Russian scientists, but their failure to fit into the framework of nineteenth-century concepts did nothing to increase his reputation in the scientific circles of his homeland. When Pekarskii wrote his lengthy biography of Lomonosov in 1873,

1. *Histoire de la Chimie* (Paris, 1869), VIII, 367.

2. Alexander Vucinich, *Science in Russian Culture* (Stanford University Press, Stanford, Calif., 1963), p. 114.

he sought to evaluate the latter's contributions through the comments of later specialists. He was able to find only two physicists who had attempted a review of Lomonosov's work. One of these, D. M. Perevoshchikov, had said in 1833: "We may accept or not accept the ideas of Lomonosov, but we cannot fail to see in his explanations a strong and ingenious logic."[3] In 1855 the physicist Lyubimov emphasized that Lomonosov was not a mathematician and said: "No particularly notable discovery is associated with the name of Lomonosov; we do not even encounter his name in the history of science. The variety of his examples which he discussed with boundless acuteness led his attention from one point to another and did not allow him to remain on a particular investigation of any separate phenomenon; he was always carried away into the field of theory."[4] With regard to Lomonosov's chemical work, Pekarskii had to admit that "until now none of our specialists has taken the trouble to consider and evaluate the nature of Lomonosov's work as a chemist from the historical point of view, and so in the present case I have had to use a rather superficial sketch."[5]

It is not surprising under these circumstances that the name of Lomonosov was not associated with corpuscular and kinetic theories after his death, and that he could be hailed as a major scientist only after the rediscovery of most of his scientific writings. If we are to look for an influence which he may have exerted on the development of science, we must determine how much his work was known to his contemporaries, and how their reactions to it may have influenced their own work.

It is also important to note his continually growing reputation among Soviet historians of science. They have claimed for Lomonosov priority in the statement of a number of major scientific laws and have tried to trace his influence in the thinking of later scientific innovators. These claims have been criticized by other writers. It is therefore desirable to review this literature in an attempt to assess the significance of Lomonosov's work.

3. P. P. Pekarskii, *Istoriya Imperatorskoi Akademii Nauk v Peterburge* (St. Petersburg, 1873), II, 447.
4. *Ibid.*, pp. 447-448.
5. *Ibid.*, pp. 451-452.

Introduction

The Academy of Sciences in St. Petersburg was recognized by all European scientists as a major scientific institution. The fact that many of the academicians already had established reputations in the West before they went to Russia and corresponded regularly with their Western colleagues helped to spread knowledge of the work of the Academy throughout the scholarly world. The use of Latin as a universal language permitted ready understanding of their papers. Thus it is not surprising that the publications of the Academy were noted, abstracted, and commented upon by most of the learned journals of Europe. These included such major publications as the *Journal des sçavans,* the *Journal encyclopédique,* the *Nova Acta Eruditorum,* and a considerable number of other scholarly journals, especially in Germany. The discussions of Lomonosov's theories in some of these journals were quite lengthy.[6] This is why Lomonosov could indignantly say of one of his critics: "He appears to have designed to impose formally on the learned world the thought that the Memoirs of the Imperial Academy at St. Petersburg is a rare work which no one is able to consult" (see p. 283).

It is true that some of the comments on his theories were extremely critical. These theories were too novel to be accepted by the more conventionally minded reviewers in some of the journals in Germany.[7] In particular, the anonymous reviewer in the Leipzig journal *Commentarii de rebus in scientia naturali et medicina gestis* for 1752 attacked all of the Lomonosov papers published in 1750 in the first volume of the *Novi Commentarii Academiae scientiarum imperialis Petropolitanae.* He was particularly violent in his criticism of the theory of the cause of heat and cold. Lomonosov obviously considered this important enough to answer in angry words. In 1754 a certain Arnold defended a thesis at the University of Erlangen, "On the Impossibility of Explaining Heat by Rotary Motion of Particles of a Body around Their Axes," in

6. References to Lomonosov in the various journals have been collected and translated into Russian in G. E. Pavlova, *M. V. Lomonosov v Vospominaniyakh i Kharakteristikakh Sovremennikov* (Academy of Sciences Press, Moscow and Leningrad, 1962), pp. 151-222.

7. Pekarskii, *Istoriya,* pp. 446-447, suggests that this criticism may have been partly instigated by some of Lomonosov's enemies in St. Petersburg.

which he specifically attacked the Lomonosov theory.[8] These criticisms indicate that Lomonosov's views were considered sufficiently important to refute, and the resulting polemics must have called further attention to the work of the Russian scholar.

Besides this, Lomonosov was in constant correspondence with Euler in Berlin, and Euler was favorably impressed with the work of his friend. In addition to inducing him to take part in the competition for papers on the origin of niter, he frequently wrote encouraging letters both to Lomonosov and to officials of the Russian government, and Lomonosov himself sent lengthy reports of his scientific work to Euler. Euler's circle of friends must therefore have been informed as to Lomonosov's work.

Popular attention was attracted to the Russian Academy and to Lomonosov himself when some spectacular event occurred. The two incidents most commented upon were the death of Lomonosov's colleague Richmann, who was killed by lightning while attempting to perform a variation of Franklin's experimental demonstration of the electrical nature of this phenomenon, and the freezing of mercury by Braun in 1759. Lomonosov took part in both these experiments. They were widely discussed in the general press and in scientific journals.

Evidence that by the time of his death in 1765 Lomonosov's fame had reached even as far as North America is given by a letter to him written in 1765 by Ezra Stiles, later president of Yale, but then a minister in Newport, Rhode Island. He described weather conditions in America and asked Lomonosov to furnish comparable data for Russia.[9] The letter was to have been forwarded by Benjamin Franklin, but Lomonosov died before it reached him, and it remained among Franklin's papers in Philadelphia.

It can be seen that Lomonosov's name was not unknown to scientists in his own day, though they certainly did not appreciate the range and originality of his speculations. Since, however, his scientific reputation did not long survive him, it

8. Pavlova, *Lomonosov,* p. 129.

9. H. M. Leicester, *Voprosy Istorii Estestvoznaniya i Tekhniki* (1962), pp. 142-147.

is necessary to trace his influence on later developments in science mostly by inference. It is this which the Soviet historians of science have done, and it is necessary to review their reasoning in order to evaluate it.

Perhaps the most speculative argument was that presented by Dorfman in 1951.[10] He noted that Kirwan, in his introduction to the English translation of Scheele's *Air and Fire,* observed that Macquer had adopted a kinetic theory of heat. Dorfman pointed out that in his *Eléments de Chymie* of 1749 Macquer explained heat as due to the presence of a fire material, but in his *Dictionnaire de Chymie* of 1766 he adopted the kinetic theory mentioned by Kirwan. Dorfman believed that Macquer took this theory from the Lomonosov paper of 1750. There is actually no evidence either for or against this speculation.

A more important suggestion was then offered by Dorfman,[11] when he observed that Lavoisier might have been influenced by Lomonosov's theories. The basis for this argument lies in the fact that Lavoisier in his paper "On Combination of Fire Material with Evaporating Liquids" of 1777[12] refers to a number of related papers, including one by Richmann on the cooling of liquids by evaporation which appeared in the *Novi Commentarii* for 1750, and he advises his readers to consult these papers. The same volume of the *Novi Commentarii* contains Lomonosov's "Meditations on the Cause of Heat and Cold." According to Dorfman, "It seems impossible that Lavoisier could have had in his hands the volume of the *Novi Commentarii* and read the paper by Richmann which he mentioned without noting the work of Lomonosov." Dorfman also pointed out that in reviewing the work of those active in developing the corpuscular theory, Lavoisier and Laplace referred to physicists who maintain that heat comes from a heat fluid

10. Ya. G. Dorfman, "The Role of Lomonosov in Development of the Kinetic Theory of Heat," in *Lomonosov Sbornik Statei i Materialov* (Academy of Sciences Press, Moscow and Leningrad, 1951), III, 45-47.

11. *Ibid.,* pp. 44-45; and also in Dorfman's *Lavuaz'e,* 2nd ed. (Academy of Sciences Press, Moscow, 1962), pp. 136-140, 190-191. For a criticism of this view, see P. Pomper, *Ambix 10,* 119-127 (1962). It is further discussed by H. M. Leicester, *Isis 58,* 240-244 (1967).

12. *Mémoires de l'Académie des Sciences* (Paris, 1777), p. 424.

and others who say it is only the result of insensible movements in the molecules of materials. Though the French writers mention no names, Dorfman is probably correct in suggesting that the last statement refers to Boyle, Bernoulli, and Lomonosov. It would certainly refer to Boyle and Bernoulli, and if the argument Dorfman is presenting is correct, also to Lomonosov. Dorfman further points out that in discussing his corpuscles, Boyle used a number of synonyms for them, referring to them as "insensible," "invisible," "minute," or "small." Lomonosov, whose view of his corpuscles was very similar to Boyle's, used the phrase "insensible particles" only, and Lavoisier and Laplace also used this term exclusively. He therefore suggested that they took the term from Lomonosov. Much of this evidence is speculative, but the fact that Lavoisier read Richmann's paper—a paper very similar to one of Lomonosov's dealing with a subject close to Lavoisier's own work—certainly is the strongest indication that he had seen the Lomonosov paper. Dorfman believes the reason Lavoisier did not mention Lomonosov was that the latter approached the problem from a physical point of view, while Lavoisier was thinking chemically. That this is probably the correct answer is shown by a closer examination of some of Lomonosov's papers.

There can be little doubt that Lavoisier would have been attracted by the title "Meditations on the Cause of Heat and Cold" for this was obviously related to his own work. However, if he began to read it, he would soon find that it seemed to be concerned only with physical theory. There are thirty-five numbered paragraphs in the paper, but it is not until paragraph thirty-one that Lomonosov begins to consider a specific chemical problem, the question of the existence of elementary fire particles. Here he discusses the gain in weight of metals in combustion and argues against Boyle's view, but at this point his only positive suggestion is that the gain in weight is due to "particles flying around in the air which continuously flows around the calcining body." This picture does not differ essentially from those given by Mayow in 1674 and by Hooke in the *Micrographia* of 1665, and so Lavoisier would probably not have considered this a novel argument. He was, of course, unaware of Lomonosov's experimental disproof in 1756 of Boyle's evidence for the addition of fire particles to metals,

since this was not published. If he read Lomonosov's only published purely chemical paper, "On the Luster of Metals," he would simply have been further convinced that Lomonosov was merely another believer in phlogiston. Therefore, in developing his own system, in which he gave an important place to caloric, another name for the matter of heat, he could not have been expected to acknowledge a debt to Lomonosov, since he did not owe one. This is a further example of the difference in thinking of a chemist and a physicist.

How then should we assess the significance of Lomonosov in science? There is almost no evidence of a direct connection of his work with that of any of his successors. He was in a sense unfortunate in that he was among the last of the great group of natural philosophers who saw the world in terms of atoms and their kinetic movements. In his day the concept of the ether, stemming from Descartes's second matter, was being transformed from that of a particulate substance into an "imponderable fluid." By the end of the eighteenth century, most scientists pictured incomprehensible phenomena such as light, heat, and electricity as fluids whose properties were explained by their flowing motion. Their particulate structure, if they had one, was of no more importance to these scientists than is the molecular structure of water flowing through a pipe to the hydraulic engineer. The suggestions of even such great figures as Boyle and Bernoulli that air was a mass of corpuscles were disregarded. It is no wonder that Lomonosov's relatively few published expositions of his theory were also disregarded. Yet the corpuscular viewpoint did not die. In a sense it went underground, but it did not completely disappear. Instead it divided into two branches.

On the one hand, a few thinkers from time to time revived the kinetic theory of gases, and the names of Le Sage and Herapath come to mind as isolated figures who maintained this idea.[13] On the other hand, there were always a few who maintained a kinetic concept of heat, and even those who believed strongly in the caloric theory were forced to note that some philosophers still adhered to an explanation of heat as

13. G. R. Talbot and A. J. Pacey, *British Journal of the History of Science 3*, 133-149 (1966).

the result of some sort of vibration of particles. Typical of these was Seguin, who in his long memoir on caloric[14] noted that Lavoisier and Laplace had declined to take a position as between the two theories, and remarked that "other physicists, though in small number, think there is no substance at all to which we can give the name caloric, and that heat is the result of insensible movements of the molecules of matter." Caloric was never universally adopted.[15]

It was not until the mid-nineteenth century that these two branches were reunited in the modern kinetic theory. Lomonosov was almost the last of the early scientists who recognized the essential unity of the two branches, and for this he deserves credit.

Finally, then, the significance of Lomonosov's work can be appraised from two aspects. In his own country he exerted a considerable contemporary influence, as has been pointed out by Vucinich.[16] At a time when there was almost no native science in Russia, Lomonosov fought vigorously to establish one. By his one work and example, as well as by his struggles to defend native Russian scientists against the entrenched German party in the Academy, he strengthened and encouraged the intellectual and scientific life of his nation. His work opened to his contemporaries the importance of science in the culture and progress of a modern state and brought them closer to Western European ideas. The example of his activity has increasingly been held up to later generations by Russian historians as a guide to be emulated. Intensely patriotic as he was, he would be pleased to know of his present recognition in the Soviet Union.

Besides this, his work is of considerable interest for its own sake. It reveals a keen and logical mind, well acquainted with the principles of the science of the day, but working in relative isolation and thus not bound by conventional scientific ideas. The general theories of the kinetic motion of corpuscles held by Lomonosov were not original with him, but his strict deductions from these were his own. Sometimes his deductions

14. A. Seguin, *Annales de chimie 3,* 182 (1789).
15. For later ideas on this subject, see F. Cajori, *Isis 4,* 483-492 (1922).
16. *Russian Culture,* pp. 110-112.

led him to surprisingly modern concepts, and sometimes they led him to seriously erroneous conclusions, but always they showed the originality of his thought. Only the study of his papers can reveal the full stature of the man.

The Papers of Lomonosov on Corpuscular Theory

INTRODUCTORY NOTE

The papers translated in the following pages have been reprinted from the originals several times in the U.S.S.R. In preparing this translation, use has been made of *Lomonosov Polnoe Sobrannie Sochinenii (Complete Collection of Papers of Lomonosov),* published by the Academy of Sciences, Moscow and Leningrad, in ten volumes between 1951 and 1959, and hereafter referred to as the *Collected Works,* and *M. V. Lomonosov Izbrannye Trudy po Khimii i Fizike (M. V. Lomonosov: Selected Works on Chemistry and Physics),* edited by A. V. Topchiev, published by the Academy of Sciences, Moscow, 1961, hereafter referred to as the *Selected Works.* In the *Collected Works* both the Latin versions and Russian translations are given for all papers originally written or published in Latin. The *Selected Works* contains only the Russian texts. In preparing these translations, the Latin and Russian texts were compared.

The first two of the following papers were not published by Lomonosov, but represent Lomonosov's corpuscular concept of chemistry and are therefore given as a background for his later writings. The remaining papers are presented in essentially chronological order to indicate the development of his thought. The places and conditions of first publication or composition are given in the introduction to each paper.

Elements of Mathematical Chemistry

This incomplete work is one of the earliest examples of the ambitious tasks which Lomonosov set for himself, and which he was unable to finish. Nevertheless, he revealed here his concept of chemistry which he modified, but never basically changed, in his later works.

The work was written shortly after Lomonosov returned from his Western European travels. It was composed in Latin between September and December 1741, with the title *Elementa chimiae mathematicae,* and was never published. The manuscript remained in the archives of the Academy of Sciences in St. Petersburg until it was discovered and published in Russian translation by B. N. Menshutkin in 1904. Although it obviously could not have influenced scientific thinking in its day, it is basic to an understanding of Lomonosov's thought as revealed in his later published writings since it defines the terms he used. The stress on the importance of mechanics in chemistry, the corpuscular definitions, and the mathematical format of the work are significant indications of his approach to chemistry.

The Latin text and its Russian translation are given in *Collected Works,* I (1950), pp. 65-83. The Russian translation is also given in *Selected Works,* pp. 7-18.

INTRODUCTION

Definition I

1) Chemistry is the science of changes occurring in mixed bodies since they are mixed.

Scholium

2) I do not doubt that there are many to whom this definition will seem incomplete and who will complain at the absence of principles of separation, combination, purification, and other expressions which fill almost all chemical books; but those who are shrewder will see that these expressions which a great many chemical authors use to excess without necessity for their studies can be included in one phrase, mixed bodies.

In fact, with an understanding of mixed bodies we can explain all their possible changes, including separations, combinations, etc.; we can exclude crude and organic substances and how cereals are broken up and ground, the growth of plants, circulation of blood in animals.

Corollary

3) Since in science it is accepted that we demonstrate truth, then in chemistry every statement should be demonstrated.

Definition II

4) The practical part of chemistry consists in historical knowledge of the changes of mixed bodies.

Scholium

6)[1] The practical part of chemistry, as in the other sciences, is a particular method of knowing: as from some of the data of numbers arithmetic finds others (§2, Elements of Arithmetic [of Wolff]) so also through the practice of chemistry new bodies are produced from several starting substances. In this way almost all the truths known up to now in chemistry have been discovered.

Definition III

7) The theoretical part of chemistry consists in a philosophical knowledge of the changes of mixed bodies.

Definition IV

8) Chemistry is that which has knowledge of the changes of mixed bodies since they are mixed.

Corollary

9) This means that whoever speaks of chemistry should demonstrate it.

Definition V

10) A practical chemist is one who has knowledge of the historical changes which occur in mixed bodies.

1. [Point 5 is omitted in the numbering of the manuscript.]

Definition VI

11) A theoretical chemist is one who has a philosophical knowledge of the changes which occur in mixed bodies.

Scholium

12) If, for example, someone knows that in a vessel filled with water or some other liquid and placed on the fire, boiling can occur, and in fact carries out this operation, he will be called practical; but if he knows that water is brought to boiling by air expanding in it from the fire and escaping from it, he will be called theoretical.

Theorem I

13) A true chemist should be theoretical and practical.

Demonstration

A chemist should demonstrate everything that is spoken of in chemistry (§8). Yet what he demonstrates must first be recognized by him, that is, he must acquire historical knowledge of the changes of mixed bodies, and hence be practical (§10). This comes first. Further, he should be able to demonstrate his knowledge (§9), that is, to give an explanation, which assumes philosophical knowledge (§).[2] Hence it follows that a true chemist should also be theoretical (§11). This comes second.

Corollary I

14) Hence the true chemist should also be a philosopher.

Corollary II

15) One who engages in practice alone is not a true chemist.

Corollary III

16) But one who delights only in speculation also cannot be considered a true chemist.

Lemma I

17) All changes of bodies occur by motion.

2. [The number is omitted in the original.]

Scholium

18) This was shown by the illustrious W[olff].

Corollary I

19) Hence changes of mixed bodies also occur by motion.

Scholium

20) This motion is in great part insensible and the reason for it cannot be perceived by the senses; therefore it is necessary to study it by reasoning.

Corollary II

21) The science of motion is mechanics; therefore the change of mixed bodies occurs mechanically.

Corollary III

22) And therefore these changes can be explained by the laws of mechanics.

Corollary IV

23) Actually, the quantity of motion can be determined by the aid of mechanics, and determination of the quantity is more truly recognized. Therefore changes in mixed bodies can be more truly recognized by the aid of mechanics.

Corollary V

24) Therefore, if anyone wishes the deepest understanding of chemical truth, he must study mechanics.

Corollary VI

25) And since a knowledge of mechanics assumes a knowledge of pure mathematics, then striving for a closer study of chemistry requires an adept in mathematics also.

Scholium

26) The light which mathematics can cast on the spagyric science can be foreseen by anyone who is devoted to its mysteries and also knows the chief natural sciences that are successfully treated by mathematics, such as hydraulics, aerometry,

optics, etc. Everything that up to then in these sciences was dark, doubtful, and uncertain has been made clear, valid, and evident by mathematics. It is true that many deny the possibility of establishing mechanical principles as the basis of chemistry, and deny it a place in the number of sciences, but they are led astray by dark occult properties and do not know that in the changes of mixed bodies the laws of mechanics are always found; they are also dissatisfied by vain and false speculations which are imposed on the learned world without any preliminary experiments by other theoreticians who misuse their time. If those who for all their days had been darkened with smoke and soot and whose brains had been dominated by chaos from masses of undigested experiments had not refused to accept the most noble laws of geometry, which were once based strictly on Euclid and at the present time have been perfected by the illustrious Wolff, they certainly would have penetrated more deeply into the secrets of nature which they themselves had announced. In fact, if mathematics has led to truth by the comparison of several different paths, then I do not see any reason why for chemistry also it could not lead to greater generalizations from such huge existing masses of experiments.

Scholium II

27) Since I have had to speak of this, I intend to state the principles of mathematics and philosophy that I consider appropriate to establish several philosophical and mathematical axioms which I will often quote in the corresponding places where they must be introduced at one or another point.

Axiom I

28) The same thing cannot simultaneously be and not be.

Axiom II

29) Nothing can occur without sufficient reason.

Axiom III

30) The same things equal each other.

Lemma II

31) The whole equals all of its parts taken together.

Lemma III

32) Common attributes of singularity depend on the same cause.

Demonstration

Attributes depend on substance (Wolff, Philosophia prima sive ontologia methodo scientifica pertractate qua omnis cognitionis humanae principia contineatur, §157); the same substance has singularity since it belongs to one type (Ontologia, §254), hence common attributes depend on the same substance. Thus there is sufficient basis for substances in common (Ontologia, §851), that is, there is one cause.

Definition

33) Change of mixed bodies, since they are mixed, is a change in their internal qualities.

Scholium

34) By internal qualities I understand everything which can be perceived in the body by the senses except form, motion, and the position of the whole body.

Corollary I

35) In chemistry, therefore, we must show change of inner qualities (§1, 3).

Corollary II

36) Since demonstration of the assertions should be drawn from a clear idea of the thing itself, we must have a clear idea of the inner qualities of the body for a discussion of that which is considered in chemistry.

Corollary III

37) Therefore part of the work should be an explanation of the inner qualities of bodies.

Definition

38) An element is part of a body which is not composed of any other smaller body which differs from it.

Definition

39) A corpuscle is a collection of elements which constitute one small mass.

Definition

40) Corpuscles are homogeneous if they consist of the same number of the same elements combined in the same way.

That such sorts of corpuscles exist is indicated by the homogeneity of mass of a body in which each part is like the whole. In fact, if they did not exist, such masses would not exist since the corpuscles would be different at any given place and would thus act differently on our senses and hence any corpuscle would be unlike any other, that is, homogeneous masses would not exist, which contradicts experience.

Corpuscles are heterogeneous when their elements are different and are differently combined or are in different numbers. On this depends the infinite variety of bodies.

A principle is a body composed of homogeneous corpuscles.

A mixed body is one which consists of two or more different principles combined with each other so that each of the separate corpuscles has the same relation to the parts of the principle of which it is composed as the whole mixed body to the whole separate principles.

Corpuscles composed directly from the elements are called primary.

Corpuscles composed of several primary ones and also different ones are called derived.

Thus, mixed bodies consist of derived corpuscles.

Compound bodies are those which consist of mixed bodies mingled with each other.

In discussing chemistry we must present demonstrations, and they should be drawn from clear presentations of the subject itself. A clear presentation should be obtained by an enumeration of the attributes, that is, by recognizing the parts of the whole; therefore it is necessary to recognize the parts of the mixed body, which are best of all recognized by considering them separately; but since they are especially small, they cannot be separated in mixtures, and they must be separated for recognizing mixed bodies. However, separation assumes a shift in

place of the parts, that is, they are moved. Hence for recognizing and demonstrating true chemistry it is necessary to know mechanics.

GENERAL PART: WHAT EXISTS AND IS PERFORMED IN MIXED BODIES[3]

Book 1. That which exists.

1. General positions. 2. On the nature of the constituent parts of mixed bodies. 3. On weight. 4. On cohesion. 5. On color. 6. On heat and fire. 7. On elasticity. 8. On sound. 9. On taste and smell.

Book 2. On that which is performed.

SPECIAL PART: ON MIXED BODIES IN PARTICULAR

Book 1. Basic propositions.
Book 2. On water.
Book 3. On earth.
Book 4. On the universal acid.
Book 5. On phlogiston, on poisons.

Separately in the second part: weight of bodies, their mass, cohesion.

3. [This table of contents indicates what Lomonosov hoped to present in his completed work.]

Introduction to the True Physical Chemistry

Between 1742 and 1750 Lomonosov developed and expanded his idea of chemistry in terms of the corpuscular theory to which he was devoted. His preoccupation with the physical properties of "mixed bodies" naturally led him to stress these properties when he developed a course in chemistry to be given to students at the university associated with the Academy of Sciences. Therefore it is not surprising that he should refer to his course as one in "physical chemistry," a term which he was the first to use. As was often the case, Lomonosov did not complete his work, and, in fact, the manuscript that has been preserved breaks off in the middle of a sentence. Nevertheless, it is one of the longest works of its type which he wrote and it shows how much his ideas had grown since the writing of "Elements of Mathematical Chemistry."

This *Prodomus ad verum chymiam physiciam* was presumably prepared for the course which Lomonosov actually gave at the university from 1752 to 1754, but it remained unpublished until 1934. While no longer written in the form of a mathematical treatise, it is still based on mechanics, and the thinking shown here is that which formed the background for the purely scientific papers which were written somewhat earlier. The Latin text and Russian translation are given in *Collected Works,* II (1951), pp. 481-577. The Russian translation is also given in *Selected Works,* pp. 176-219.

CHAPTER 1. PHYSICAL CHEMISTRY AND ITS PURPOSE

§1

Physical chemistry is the science which explains whatever occurs in mixed bodies through chemical operations on the basis of the principles and experiments of physics. It can also be called chemical philosophy, but in an entirely different sense than the mystical philosophy in which explanations not only are hidden, but even the operations themselves are carried out secretly.

§2

We have ventured to call this work physical chemistry be-

cause we have decided, by devoting all our efforts to it, to bring together in it only what is contributed by a scientific explanation of mixed bodies. Therefore we consider it necessary that everything relating to the sciences of economics, pharmacy, metallurgy, glassmaking, etc. should be excluded from it and assigned to the course in technical chemistry so that 1) everyone will easily find the information which he needs and will read it without boredom; 2) the memory will not be overburdened by studying so many different cases; 3) philosophical contemplation of the beauty of nature will not be corrupted by a rash desire for gain; 4) the studious cultivator of chemistry will approach it with a clear understanding of mixed bodies in order to increase the conveniences of life by its aid.

§3

We call chemistry a science in imitation of the writers on natural philosophy who, though they explain only the most important phenomena of nature, so that very much remains doubtful and still more remains unknown, nevertheless correctly embellish physics with the name of a science on the basis not of knowledge, but of the final ends of physics. For no one can deny that however little we have succeeded in explaining chemical phenomena by the methods of physics, we should properly use these methods with the same right as does physics itself.

§4

We have said that chemical science considers the qualities and changes of bodies. Quality has a double nature, namely, one which produces visible ideas in us, the other only sensible ones. The first type of quality includes mass, shape, motion or rest, and place position of each perceptible body; the second type includes color, taste, healing power, cohesion of particles, etc. The first are perceptible to the eye and are determined by geometrical and mechanical laws, examples of which they demonstrate; the causes for the second type lie in the particles which do not reach the sharp vision and therefore these qualities cannot be determined by geometry and mechanics without the help of physical chemistry. The first by necessity are present in all bodies, the second only in some. Therefore we consider

it desirable, according to the style of Boyle, to call the first qualities universal, the second, particular.

§5

A mixed body is one which consists of two or several heterogeneous bodies joined to each other in such a way that any sensible part of this body is exactly like any other of its parts with respect to particular qualities. Thus, gunpowder consists of niter, sulfur, and charcoal, heterogeneous types of bodies, and any part of it, evident to the senses, is exactly like any other part in color, cohesion of the parts, explosive power, etc. Bodies which make up mixed bodies, here niter, sulfur, and charcoal, are called constituent bodies.

§6

Constituent bodies are often themselves mixed bodies consisting of other heterogeneous bodies; thus in this case sulfur consists of an acid material and another, the combustible one; niter consists of a particular acid and an alkali salt; charcoal of an oil, a bitter acid spirit, and an ash. Constituent bodies of such a nature we call constituents of the second order, and if they in their turn are mixed bodies, then we call their constituents constitutents of the third order. We cannot, however, proceed thus to infinity, but there must finally exist constituents which it is impossible to separate from each other by any chemical operation or to distinguish by reason; therefore such constituent bodies are designated as the final ones, or, in the language of the chemist, principles.

§7

Since mixed bodies are like each other in all sensible parts (§5) then it follows that any sensible particle of them is composed of the same constituents; therefore in mixed bodies there should be particles which, if submitted to further separation would split into different particles of the heterogeneous bodies of which the mixed body consists. The first particles we call particles of the mixed body, the second, particles of the constituents. The first type is represented by particles of gunpowder which can be split only into sulfur, niter, and charcoal; the second type is represented by the particles of niter, sulfur,

and charcoal themselves which in the gunpowder form the particles of the mixed body. It is appropriate to call the particles of the ultimate constituents the particles of principles.

§8

From the definition of a mixed body and the examples, it follows that different qualities and phenomena arise from heterogeneous mixed bodies and therefore to explain the particular qualities of bodies and their changes we must have knowledge of their composition. Hence the duty of chemistry is to study both the composition of bodies available to the senses and the composition of those from which the mixed bodies were first formed, namely, the principles. The following chapters will show by what path, by what chemical means and physical help this can be done.

CHAPTER 2. THE PARTICULAR QUALITIES OF MIXED BODIES

§9

In the first place we must establish those qualities of the mixed bodies which depend on different cohesion of the particles, for no changes of mixed bodies in chemistry can occur without change in the cohesion of the particles.

§10

From different cohesion of the particles first of all arise solid and liquid bodies. Solid bodies are those whose shape cannot be changed without external force, and liquids are those whose particles slip around each other by their own weight and which form an upper surface parallel to the horizon, and the rest of their particles acquire the shape of the hollow which contains this body.

§11

Solid bodies are hard or ductile. Hard bodies under the force of a blow are split into pieces; ductile ones yield to a blow not by breaking, but by being drawn out into a sheet or wire. In both cases the quality of the resistance differs according to the

cohesion between the particles, and it cannot in any way be definitely set, since it can be infinitely varied.

§12

A hard body is rigid or brittle. A rigid body requires great force and tools for breaking up the cohesion of the particles; a brittle one is broken by pressure or by squeezing it with the fingers. Finally, a brittle body can crumble or be cracked. When the body is crumbled, it is split by the application of force into grains or into a powder, as we see in the case of marble and dry clay. When a body is cracked, it breaks up into platelets of very fine fibers, as we see in the case of selenite and asbestos.

§13

A liquid body is either viscous or thin. A thin one quickly follows the surface of the cavity containing it when this is changed; a viscous one does so slowly. Water belongs to the first type, tar, honey, etc. to the second.

§14

Physicists also distinguish liquid from fluid bodies. They call liquid those bodies whose cohering particles flow and form drops, like water. Fluid bodies are those which change in a special way, whose particles slide without cohesion. Such a body is alabaster which changes into a powder when it is calcined.

§15

It seems likely, if it is not always so, that in solid bodies the flexibility depends chiefly on the cohesion of the particles. Flexibility is the quality of bodies by virtue of which their shape, changed by external pressure, is restored to the original: such as fibers of iron, glass, etc.

§16

As the flexibility of solid bodies comes chiefly from the cohesion of the particles, so on the property of the flexibility of solid bodies itself depends their sonorousness, which is defined as the sensible continuation of sound after imposing a blow on the body. Bodies with this property are called sonorous, such

as bronze, iron, etc. It is shown by everyday experience that the sonorousness in bodies of different sorts is different and the mass and shape have a very great effect on strengthening or weakening it.

§17

After discussing the qualities which depend on difference in cohesion of the particles, we must next establish those which act on the sense of vision. This is necessary because of the nobility of the corresponding sense organ and the almost endless variety of these qualities. There is not one mixed body, whether extracted by the tireless work of mortals from the subterranean kingdom of nature, or obtained from the brilliant treasury of the flowers, or, finally, prepared from the parts of animals, whose color, glittering lively luster or rough, pleasant appearance or wonderful variety cannot be imitated by the work of the chemist.

§18

The eye distinguishes most clearly of all an opaque body from a transparent one. An opaque body is one which, when placed between the eye and an object, does not permit the image of the latter to be reproduced in the eye. A body is called transparent if, when placed between the eye and an object it passes the image clearly and distinctly to the eye. The first type of body includes marble, metals, etc., the second, water, quartz, and things similar to them. This definition is not altered by different shapes into which the transparent body is changed or multiplied by refraction of light: in chemistry we consider the mixed body to be transparent and not its superficial differences.

§19

Transparent bodies do not always transmit to the eye with equal clarity the image of an object placed beyond them, but it is often seen, as it were, wrapped in a cloud. Such clouding or darkening occurs differently and differs in degree for different bodies, so that one is less clear than another, and finally they gradually approach an opaque body. Those which occupy a middle position between transparent and opaque and pass

such jumbled light that the form of the object which is transmitted is run together are called semitransparent, like the mineral chalcedony, fish glue, and similar bodies.

§20

Transparent and opaque bodies are smooth or rough. A smooth body gives on itself an image of an object presented to it; a rough body does not give this. Smooth bodies here are those bodies which assume a smooth surface without the intervention of human work, such as water, ice, mercury, opaque and transparent glass; rough bodies are like marble at the point of fracture, dry clay, and similar substances. From mirror smoothness to roughness which entirely prevents an object from giving an image on the surface of the body there are evidently almost infinite degrees of smoothness; the images of the objects are reflected with differing clarities, just as there are differing transmissions through semitransparent bodies.

§21

We have noted that smooth bodies may be shining or lustrous, and we make a distinction, defining shining bodies as those which, being exposed to daylight, reflect parallel white light, whatever their own color, and we call those bodies lustrous which on exposure to daylight, reflect parallel light of the same color as themselves. We find the first in glass, the second chiefly in metals. Placed opposite a window the smooth surface of glass, even if very black, gives a white image of the window, but gold a yellow one, copper a reddish one.

§22

It is impossible to give a definition of the colors by which bodies act on our eyes, or to enumerate their variety. But it is quite certain that there exist some colors which originate from others, mixed with each other, and some which cannot be obtained by this method. Thus we can make up an orange color from red and yellow, green from yellow and blue, violet from blue and red, but red, yellow, and blue can be created from no others, as is clearly shown by mixing colored powders or by blending the sun's rays, about which we will speak in more detail in the theoretical part (§ . . .). Therefore red, yellow, and

blue colors are called simple and all other colors except black (which is not a color) are called mixed.

§23

Since mixtures of simple colors can be varied almost endlessly, we can obtain an almost endless number of mixed colors, for the designation and clear distinguishing of which we evidently lack names, number, or measure. Therefore for describing the colors of chemical bodies so that the reader can understand correctly and clearly, we will define the different changes in the quality of colors by comparison with substances of constant color.

§24

Thus, in order to distinguish most clearly the simple and pure colors from the others, we will call red that color which we see in blood, in hydrangea petals, in wool colored with carmine, and in minium; yellow is the color found in an infusion of saffron, in camomile, and in the best ocher; finally, blue, present in the clear sky, is in cornflowers and blue ultramarine powder. Thus we will call the first color red, bloody, or carmine, the second yellow and saffron, and, finally, the third blue, cornflower, or ultramarine.

§25

Between these colors there are also three: the first consists of bloody and saffron, the second of saffron and blue, the third of blue and bloody, mixed in equal parts. There is a sufficient similarity to the first color in orange peel, and in the petals of a large African flower; the second in green meadows; the third in turquoise; therefore we call the first orange, the second green or herbaceous, the third turquoise. From the three simple colors combined in proper proportions we obtain white; the absence of all color is the cause of blackness. This is all clearly discussed in optics, and we intend to discuss this in more detail in the theoretical part.

§25[1]

As we have established the differences between the chief

1. [In the manuscript there are two § 25's and no § 29.]

varieties of color by comparing them with substances, we consider it expedient to describe all the other colors originating from different and unequal mixtures of the simple colors and from different brightnesses of color by comparing them with generally known substances and denoting the intensity of the predominant color.

§26

After we have described the sense of the eye, we proceed to differences in the sense of the tongue which we call different tastes. A substance is said to have taste when it causes a pleasant or unpleasant sensation on the tongue, and to be tasteless when it does not do this. The chief and very distinctive tastes are: 1) acid, as in vinegar; 2) burning, as with spirit of wine; 3) sweet, as with honey; 4) bitter, as with pitch; 5) salty, as with salt; 6) sharp, as with a radish; 7) sour, as with unripe fruit. Which of these is simple and which complex cannot be explained until we learn the nature of the principles.

§27

As for colors, so for taste we know an almost infinite variety originating from different mixtures of the tastes named above and their differing sharpnesses depending on the admixture of tasteless substances. Therefore in chemical practice we can designate bodies differing in taste just as in the case of colors, by known comparisons and by designating the tastes belonging to them.

§28

Odors, acting on the sense of smell, in great part correspond to tastes, so that, for example, that which has an acid taste also acts on us as an acid odor. For designating and characterizing odors, almost infinite in variety, we cannot do otherwise than was done for tastes.

§30

It remains to say something about the inner properties of mixed bodies which can be produced naturally or artificially—what is their ability to attract, repel, create an ignis fatuus, burn spontaneously, etc. and also their medicinal or poisonous

powers. Here it is enough to mention that everything is described in its place; when we try to study the properties of the first type in considering mixed bodies, there are suitable methods described below (§). For the second type where necessary we borrow from famous physicians because experiments for revealing them have not been instituted by chemists.

CHAPTER 3. ON THE MEDIA BY WHICH BODIES ARE CHANGED

§31

Mixed bodies are changed by addition or loss of one or several constituents (§). Here it is necessary that each corpuscle of the mixed body take up or lose one or several corpuscles of the constituents. But this cannot occur without change of the bonds of the particles. Therefore forces are required which could nullify the cohesion between the particles. Fire produces such action most easily of all: there is not one body in nature whose inner parts would be insensitive to it, and there are no mutual bonds of the particles which it could not rupture.

§32

There are five conditions which chemists should usually observe concerning fire: 1) degree of intensity; 2) its relation to the body undergoing its action; 3) length of time; 4) rate of progressive motion; 5) its form.

§33

The intensity of the fire cannot be judged by sense of touch nor by variation of the light given off by the burning body, nor by the boiling of liquids, nor by melting or solidifying of bodies. Touch is not always useful for this and is very often deceiving; a luminous body is often less hot than a dark one; thus the flame of burning oakum is less hot than iron close to glowing; mixed liquids boil when they are much cooler than some others which have not yet boiled; finally, the same fire which melts one body converts another from the liquified state into a solid. The single most certain measure of fire is found in the rarefaction of bodies, on which the thermometer and

pyrometer are based. These instruments are especially useful to the chemist for finding the intensity of the fire; but we will speak of them in detail in their own place.

§34

However, in nature there are some changes of bodies which embody as some limit a definite number of degrees of the thermometer or pyrometer and constantly correspond to the same point; it is not superfluous here to indicate them briefly, because we use these limits to establish more clearly our ideas about the intensity of the fire. It is also suitable to introduce the name of the temperature region for a known number of degrees on the thermometer or pyrometer between constant limits, so that by words used directly there is no complication and no difficulty for the reader. Therefore, first of all, heat or fire from the least to the greatest as met in nature is divided into temperature regions and these into degrees.

§35

The first and lowest temperature region begins from the lowest degree of heat, or, which is the same thing, from the greatest degree of cold, which as yet no one has observed or demonstrated. It ends at the temperature where water begins to freeze; this limit is always constant and unchanged and is based on an effect which is very important and has the greatest significance in natural affairs. Fire of this temperature region can be used scarcely or not at all by any chemist. However, we intend here to pursue some perhaps rather important chemical experiments. Below the freezing point of water many substances still remain liquid and hence have not fully lost the force needed for chemical action. The second temperature region begins where the first ends. We take as its higher limit that point which is reached by the greatest observed summer heat and about that which is found for the heat of a healthy human being. The third temperature region extends from here to the boiling point of water; the fourth is established between boiling water and boiling mercury. The fifth extends from there to the heat at which copper melts. Finally, the sixth temperature region, beginning at the melting of copper, reaches the highest degree of fire, if such exists. All the limits of tempera-

ture noted here produce important effects which have enormous significance both in nature and in chemistry itself.

§36

Similarly with respect to the properties of each body and for each chemical work the chemist should use a definite degree of fire, so that it is necessary to regulate its quantity very carefully in order not to use too little or too great an amount of fire with respect to the volume of the body used for chemical investigation. Actually, in the first case we do not attain the desired results and in the second we expend toil and labor in vain.

§37

It is also necessary to note still a third circumstance, that a weaker fire often is much more effective than a strong one for subduing a stubborn body. In some cases definite bodies are more easily broken down by time than by force. Therefore the chemist, carrying out an experiment, should consider carefully where a slow fire is needed and where a strong one.

§38

Different rates of motion found in an expanding flame help much the effect of the force of the fire. Thus we see that among goldsmiths iron wire of about the thickness of one line cannot be heated in the flame of a burner to the temperature at which iron melts if this flame is not put into swiftest motion by the breath from a blowpipe. Therefore, we must again remind the chemist that he must know how to excite motion of a flame when this is required.

§39

Different forms of using fire are: that either there penetrates into the heated body the heat alone, or the flame itself surrounds and touches the body directly. There are experiments well enough known in the practice of chemistry which occur somewhat differently because of this effect, although the same degree of fire is used in the course of the same period of time. Therefore, let the chemist note where it is necessary to use pure heat and where flame.

§40

For flames it is necessary to consider different combustible materials: whether wood or coal and whether coal or charcoal and from what wood. For how they burn depends on denseness or porousness, fatness or thinness, dryness or moisture, and the flame itself may be pure or smoking, and with other conditions equal, the effects are often changed.

§41

Fire cannot make a great difference in abolishing or weakening or in any other way changing the strength of cohesion between the particles of a mixed body if it is not helped by water or air, separately or together; it separates particles liberated from their bonds, transfers them, and interposes others between them. Thus, fire naturally changes the cohesion between particles, and air and water change their positions. Therefore the first as it were is the instrument and the other two the vehicles. We will state here in a few words the care with which we must use these terms.

§42

Air combines with mixed bodies in two ways: either flowing around them and depositing on their surfaces, or by occupying their pores. In the latter case we must speak of it as internal, in the first case, as external. The influence of either type on chemical phenomena is rather great.

§43

External air, as found immobile on the surface of bodies, often changes the mixed bodies by shifting the characteristic particles of the latter with the aid of fire, and when it is found in motion it brings foreign particles to them, particles which it carries within itself, or it carries away with itself the particles torn away from the bodies, or both processes occur at once. The faster the motion of the air, the more foreign particles are brought, or the more natural particles of the bodies are carried away.

§44

Particles carried by the motion of air to mixed bodies are either taken from the atmosphere itself or are supplied artifi-

cially by the chemist. The first differ depending on the weather, the nature and position, the number of inhabitants, and occurrence near a workshop; the second depend on the nature of the fuel used for maintaining the fire or on the nature of the body specially taken for the experiment. It is necessary in both cases that the chemist be careful: 1) not to consider the action of air identical when it comes from swampy places, in summer time, or from a place near to which much sulfur is roasted out of metals, or the action of a drier and purer air; 2) not to assume that material is added from the fuel or from any neighboring body except for what is natural to the body itself.

§45

Internal air, contained in the pores of a body, should of necessity saturate them because of the greater subtlety of its finer particles, especially if the body is sweet scented. Therefore, as soon as the particles of the body are freed from mutual cohesion they are scattered and the internal air is mixed with the external; the more subtle particles escape from the mixed body and so a considerable change in quality must result.

§46

Then the internal air, liberated from the separated body and inflated by the subtle vapors, often occupies a surprisingly large space and exerts a very strong force against an obstacle. That is why the chemist is warned, so that this inflating air, seeking an outlet may not break the vessel with damage to the work, to expensive materials, and even to health.

§47

Experiment shows that there are several forms of water distinguished by the bodies with which they are impregnated. In rain water we find one property, in river water another, and in spring water a third. When rain from on high falls through the atmosphere it takes to itself the sulfurous and salty vapors which it encounters. Therefore, if the water stands for several days in the sun in summer, a greenish tint develops; it furnishes food for plants also. River water contains salty particles

washed out from the earth, from fermenting, decaying, and burned bodies brought by the streams flowing from all sides; many of these particles are detected in the residue when the pure water vapor is scattered into the air by heat. Spring water very often, almost always, carries in itself minerals dissolved in the mountains which can often be detected by taste, sometimes by smell.

§48

How many of these impurities cause injury in chemical actions is well enough known from technical chemistry: thus, dyers, brewers, and other craftsmen complain that in their arts they cannot attain the same degree of perfection using just any sort of water. Therefore in chemical investigations carried out for a physical understanding of mixed bodies we must take only the purest water which can be found or prepared, if we do not wish to be deceived in discovering the secrets of nature.

§49

The processes by which we must purify the water will be given below. Of the natural waters the purest is most simply prepared from snow not contaminated by dust, especially from that which falls after a severe frost in quiet weather, for the surface of the earth, confined by the severity of winter and covered with snow emits salty and combustible vapors, as in summer. In second place stands river water flowing under ice in midwinter. At this time the streams generated by rains do not contain impurities, nor does dust generated by the wind make them cloudy and saturated with salty substances; but we draw it as it comes from the earth filtered through the sandy shore. The third place is held by rain water. Other water cannot be used without study and purification.

§50

Actually the changes produced by water in the composition of bodies are aggravated by the fact that water itself is the chief constituent part in many bodies, so that after its removal their form is completely altered. Therefore water used as a medium should be strictly distinguished from water which exists in the body itself as a constituent part or has considerable significance

among the other constituent parts along with which it forms the mixed body.

§51

Such are the true and genuine media without which, or especially without two of them, no changes can be produced in mixed bodies. Besides these, other authors name many more, almost an infiinite number of chemical media, as many as there are different mixed bodies which act on each other with the help of fire, air, and water. But to describe and explain them all seems to me to be the same as to give an account of all chemistry in the introduction to it before an account of it itself. Therefore we have decided to describe the interactions of mixed bodies and the different constituent parts in the place needed for each.

CHAPTER 4. ON CHEMICAL OPERATIONS

§52

Chemical operations are those processes which with the help of chemical media change mixed bodies, since they are mixed. With the aid of this definition we can easily determine which chemical operations are basic and genuine and which are only subsidiary. Thus, the first either 1) combine separate constituents into a mixed body, or 2) separate a mixed body into its constituents, or 3) simultaneously do one and the other, or 4) change the ratio of the amounts of constituents, or, finally, 5) shift the positions of the particles in the mixed body. In all cases there is a change in the individual qualities, one or several. The second operation does not lead to anything similar, but permits preparation of the body for the basic operation.

§53

We separate the basic chemical operations into general and special, or into primary and secondary. We call the six general ones: *relaxation, concretion, solution, precipitation, digestion, and sublimation.* Several are called special or secondary, and most of these were devised by chemists not because of different manners of their action, but on different materials. Excluding

all the unnecessary ones of these, we will consider the most important of them along with the primary ones, each in its place.

§54

Relaxation is weakening or even destruction of the cohesion between the particles of bodies. This type of operation is introduced and placed with the others with full reason, since 1) it changes the main qualities in bodies, 2) it opens a road to alteration of mixed bodies, and 3) it shows the different forces of cohesion between particles in most bodies.

§55

Relaxation changes most of all the position of the particles of a mixed body (§52, No. 5), although other changes occur often enough depending on the character of the different types of this operation, which number five: *melting, softening, dilution, calcination, and preparation.*

§56

Melting is the conversion of a solid body into a liquid, carried out with the help of fire. The usual example is seen in the work of the goldsmith and many other craftsmen who deal chiefly with the melting of metals. By this operation the bond between particles is most weakened, and two or more heterogeneous bodies are easily combined into one, or, if a mixed body, are separated.

§57

Softening is the change with the aid of heat of hard bodies into soft ones; it is as it were some degree toward melting; it must be distinguished from melting only because sometimes two bodies, due to their mixing, do not reach their combined melting point, for at such a strength of the fire the subtlest and most active particles have flown off into the air.

§58

Dilution is the conversion of a liquid body from a thicker to a thinner liquid by adding a more considerable amount of aqueous humor, or of other liquid resembling one of the con-

stituents of the body which is diluted. It has many varied uses, for a perfectly liquid body is more easily mixed, and heavier heterogeneous materials settle faster to the bottom, and from an extremely active substance, milder ones result. An example often seen among asayers and engravers on copper is the dilution of aqua fortis with water so that it is made milder and produces more accurate effects.

§59

Calcination is the transformation of a solid or liquid body into a powder by a strong fire. A common example can be seen in a sculptor's statue where for preparation of an image alabaster is converted by strong fire into a powder. In this operation there is complete separation of the cohering particles and a way is opened for entry of foreign bodies which can be combined.

§60

Preparation is the conversion of a strong, solid body into a powder by ignition and quenching with water, repeated several times with the aid of grinding. By this method we can break down the most resistant solid stones and make them, unconquerable as they are by other methods, soft and available for treatment. An example is supplied by jewelers who by the method described above prepare emery for polishing stones.

§61

Concretion consists in this, that particles of a mixed body which has constituents with weak or completely destroyed cohesion are converted to a state of closer mutual bonds. This operation reverses the preceding. Usually relaxation is the beginning of all experiments and concretion their end; the first opens, the second closes.

§62

The types of concretion, which in great part consists in the alteration of the position of the particles of the mixed body, are nine: *freezing, setting, thickening, crystallization, coagulation, hardening, petrification, vitrifying, and annealing.*

§63

Freezing is the transformation of a liquid body into a solid by lessening the degree of fire; an example is any metal cooled after melting, and also the freezing of water. This operation reverses melting; it is especially suitable for conversion of heterogeneous bodies combined by mutual mixing into a solid compound.

§64

Setting is the conversion of a soft body into a hard one. It reverses softening and is carried out by lessened heat.

§65

Thickening is the transformation of a thin liquid into a thick one, or even into a solid body, by removal of excess moisture. It is carried out either by gentle heat, without apparent motion of the liquid, or by stronger fire, with boiling. In the first case this operation can be called evaporation, in the second, boiling off. Common examples occur in salt making where brine is evaporated, and in confectionary shops which prepare sweets from the thickened juice of berries.

§66

Crystallization is carried out when a liquid body made thicker by evaporation or boiling off and left to stand quietly in a cold place is partly converted to solid, angular grains. Chemists use this operation for collecting together solid bodies dispersed in a liquid. Examples are found in salt making and places for preparing niter.

§67

Coagulation is the transformation of a thin liquid into a thick one or a thick liquid into a soft solid body, produced without marked evaporation. We see examples in the boiling of eggs and in the coagulation of milk.

§68

Hardening is quenching of heated metal in water to convert it from a ductile body into a strong one. This operation is very

often used among craftsmen, especially by gunsmiths, but it should also have value in physical chemistry.

§69

Vitrifying occurs when a body in the form of a powder is melted by a strong fire through liquification to a lustrous solid body which when heated can be drawn out into fibers. Examples can be seen in glass manufacture and in the laboratories of assayers; also among goldsmiths who in this way decorate necklaces, rings, etc., with enamel. By this operation many different mixed bodies are combined with strong bonds.

§70

Petrification is the conversion, by the force of fire, of a powdered body converted by water into a paste which is given a desired definite form into a stony substance which is slowly dried. This operation differs from vitrifying by the fact that here the material is not liquified and the resulting stony body does not soften on calcination and cannot be drawn into fibers. Examples are common among potters and brickmakers, but are best seen among workers with porcelain objects. The results, in the sense of forming mixed bodies, are similar to those obtained with vitrifying.

§71

Annealing occurs when a body converted into the state of a glass or stone is submitted to prolonged action of a somewhat lower degree of heat than is used in ignition, and is then gradually cooled, which assures even cohesion of the particles and lessens brittleness. Also, by the help of this operation many things are produced with a pleasant appearance from colored glass.

§72

Solution occurs when a liquid body acts on another, solid or even liquid, so that successively its particles are torn off from their cohesion and bonds to another body joined to them, and by destruction and combination, a mixed body is formed. The body which produces the solution is called the solvent by chemists.

§73

There are two kinds of solution: complete and partial. The first occurs when the dissolving body passes wholly into the solvent; the second when some constituent part is precipitated from the dissolving body by the strong solvent and combines with it. There are several varieties of the first; the second is a single one of the varieties of this operation, which number nine: *solution proper, extraction, digestion, elution, amalgamation, cementation, corrosion, deliquescence, and solution in vapor.*

§74

Solution proper occurs when particles of solid or also of a liquid body immersed in the solvent are broken off successively from the surface and are distributed throughout the solvent itself. We see an example daily when salt or sugar dissolve in water.

§75

The solution is called partial when some mixture consists of two heterogeneous bodies of which only one is dissolved in the solvent and the second, even if it is in a state of the finest particles, does not mix with the solvent; this can be seen among assayers, when gold is separated from silver with the aid of aqua fortis.

§76

Extraction occurs when the solvent, as is always the case with spirit of wine, draws out some constituent part from bodies immersed in it, and takes this into its own composition. A common example is daily found when aqua vitae is saturated with aromatic substances. The very name and definition show that this type of operation is always partial. It is distinguished from the preceding one by the fact that that type is used more for minerals, and this for plant substances; the former dissolves a greater part of the body, this dissolves a lesser part.

§77

Digestion is almost the same as extraction and differs only in the degree of fire and nature of the solvent, for here water

brought to boiling by fire is always used. The common examples, before the eyes of everyone, are seen in the kitchen.

§78

Elution is the separation of the salty parts from powdered bodies by warm water and shaking. The usual example is the alkali washed from ashes and very widely used by launderers.

§79

Amalgamation is the solution of metals or metallic bodies in quicksilver. An example can be found among goldsmiths who dissolve gold in quicksilver for gilding silver and copper objects. This operation is called partial when a mixture, one of whose constituents does not undergo the action of the solvent, is placed in this solvent.

§80

Cementation occurs when the dissolving body and the solvent are solid bodies and therefore are put in a vessel one upon the other in successive layers and are covered and submitted to the action of a known degree of heat so that the dissolving body which lies below is dissolved by the solvent and is partly or completely melted. An example is found among goldsmiths who separate gold from lower metals by salt cementation.

§81

Corrosion is that solution in which corpuscles of the dissolved body in great part fall to the bottom of the vessel in the form of a powder.

§82

Solution in a vapor occurs when the exhalations of the solvent act on a suspended body and, dissolving it, combine with it.

§83

Almost the same sort of an operation as solution in a vapor is attributed to deliquescence: this is nothing else than solution of a body placed in moist air by water vapor. An example is the frequently occurring deliquescence of common salt in moist air.

§84

Precipitation occurs when heterogeneous bodies, mixed with each other, interact so that one takes away from the other one of its constituent parts and adds it to itself, thrusting out the residue. This is often accompanied by effervescence and change in the qualities of the particles, preferably those which act on the sense of vision. It follows from the definition that precipitation occurs by the third method (§52).

§85

Precipitation in the strict sense is settling out in the form of a powder of a body soluble in the liquid when another body is added. This operation gives many and astonishing results: a common example can be seen in the preparation of ink from a solution of iron vitriol and a decoction of gall nuts.

§86

Reduction is the reverse transformation of a metal or semimetal, which has taken the form of a powder or slag, into metallike form. Many examples are encountered in assaying and even among those who are almost artisans manufacturing metallic objects. Reduction of mercury is denoted by the special name, revivification.

§87

Detonation occurs when a body undergoes the action of open fire, so that the constituent parts driven out are fired by the flame and are destroyed by it with a sudden noise. An example of this is often found in assaying when black flux is prepared.

§88

Cuppelation is the separation of gold or silver from combination with other bodies by the aid of lead in a slag crucible called the cupple. There are many examples in assaying and goldsmithing.

§89

Chemical growth occurs when, after precipitation, the separated constituent grows like some sort of plant. Such an operation is produced in chemical laboratories as, for example, in

obtaining the *arbor Dianae;* this has no value for usefulness or convenience of life.

§90

Digestion is the prolonged treatment of mixed bodies by fire or moderate, uniform heat, due to which the insensible particles of the body, set in motion, change their arrangement in the mixed body. Therefore such an operation belongs to the fifth type (§52). There are four different types: *mineral digestion,* fermentation, putrefaction, and reverberation.

§91

We call mineral digestion the operation by which in minerals treated in a closed vessel a constituent part changes its position in such a way that the part previously surrounded by another emerges. Alchemists use this operation very widely.

§92

Fermentation is digestion occurring at moderate heat by means of which substances, preferably from plants, are freed from combination with other spiritous and vinegary parts. Examples are met almost everywhere and daily.

§93

Putrefaction is digestion with very weak heat by which there is liberation from combination with other materials of the urinous constituent parts, chiefly from animal substances. Examples are met very often, even in spite of our wishes.

§94

Reverberation is a longer calcination of a body, converting it to a powder by directing a flame onto it. This operation often follows directly on calcination and therefore it may be confused with it by some who have not studied the nature of the matter sufficiently. An example of both is the preparation of minium. Here there occurs not only a shift of the constituents, but some new constituent is also added from the flame.

§95

We call sublimation in general the transfer of a body in the form of a vapor or smoke by strong fire from one place to

another. By this operation is attained 1) separation of the constituents, since those which do not withstand the strength of the fire fly upwards and those which do not yield to it remain in their place; 2) the combination of separate constituents in a mixed body; it often happens that a body which otherwise was difficult to combine is very closely bound to another when transformed into a vapor. The first case belongs to the second type, the latter to the first (§52). Bodies not converted by chemical fire into vapor are called fixed, and the others, volatile.

§96

There are four varieties of sublimation: dry sublimation, moist sublimation, or distillation, rectification, and cremation.

§97

Dry sublimation occurs when the vapor of the subliming body condenses into a solid body, hard or brittle. Examples are sulfur, cinnabar, and others which collect from the vapor in solid form.

§98

Moist sublimation, or distillation, occurs when the collected vapors in liquid form fall in drops into a receiving vessel. A common case is the preparation of aqua vitae.

§99

Rectification is distillation in which the liquid is separated from corrupt parts or from an excess of watery moisture or other impurity. Examples can also be seen in the preparation of spiritous liquors.

§100

Cremation is sublimation in which a body is burned with a bare flame and the smoke is collected in a suitable vessel. Examples are very common in every fireplace.

§101

When the enumerated and here given definitions of chemical operations are carried out at one time in related connections, the whole series is called a *process.*

§102

The precautions in the operations are many, and they differ depending on the nature of the different bodies undergoing treatment, and therefore we will describe each in its place.

§103

We must further note that we cannot carry out every operation with every mixed body, as will be evident when, in the next chapter, we speak of differences in the nature of mixed bodies.

§104

Subsidiary operations are used: 1) for breaking up; 2) for separation; 3) for combining constituent parts.

§105

Breaking up is promoted: by *lamination,* in which the body is flattened with a hammer into plates; by *crushing,* if the body is pounded in a mortar; by *granulation* when the melted body is immersed in water or, undergoing another type of action, is split into grains; by *scraping,* when it is scraped with a knife; by *filing,* when it is rubbed with a file; by *grinding,* if it is ground in a mortar.

§106

Suitable for carrying out separations are *sifting,* when the larger parts are separated from the finer ones on a sieve; *filtering,* when with the aid of a porous body a clear liquid is separated from a heterogeneous body; *sedimentation,* when a powdery body shaken in water sinks to the bottom faster or more slowly in accord with the different weights of the particles, and thus the finer particles are separated from the larger ones; *settling,* when after some time interval the material which creates a cloud in the liquid falls to the bottom; *pouring off* or so-called *decantation,* when a clear liquid is poured from a precipitate over the edge of the vessel.

§107

Carrying out mingling makes use of: *mixing,* when two liquids are mixed; *shaking,* when bodies mixed together are

shaken; *kneading,* when soft bodies are combined by rubbing together; *rubbing,* when a mixture of powders is combined by prolonged grinding.

CHAPTER 5. ON GENERATION OF MIXED BODIES

§108

All bodies are either organic or inorganic. In organic substances the bodies are constructed and bound to each other in such a way that the cause of one part is included in the other with which it is bound. In inorganic bodies the particles, aside from their reciprocal cohesion and position do not have a binding cause. Among the organic substances we here mention preferably natural bodies, namely those of the animal and vegetable kingdoms whose fibers, ducts, vacuoles, juices in their formation and organization depend on each other. Inorganic bodies which are thus mixed form the whole mineral kingdom, the greatest field of chemical materials.

§109

Also, although the organs of animals and plants are very small, yet they consist of still finer particles and these are inorganic, that is, are mixed bodies, because in chemical operations when their organic structures are destroyed, mixed bodies are obtained from them. Thus, all mixed bodies which are produced from animal or vegetable bodies, natural or artificial, also constitute chemical materials. Hence it is clear how wide are the obligations and forces of chemistry in bodies of all the kingdoms of however different a nature, so that we consider it necessary to enumerate briefly here the most important forms.

§110

The first type of mixed body consists of salts and spirits of salts, the second of sulfurous bodies, the third of juices, the fourth of metals, the fifth of semimetals, the sixth of earths, the seventh of stones.

§111

By the name salts we designate brittle bodies which are dissolved in water which then remains clear; they do not catch

fire if they are submitted in pure form to the action of fire. Their types are: vitriols and all other metallic salts, alum, borax, tartar, essential salts of plants, salt of tartar and potash, volatile urinous salt, niter, common salt from springs, sea, rocks, sal ammoniac, English salt and other salts obtained as a result of chemical work.

§112

Spirits of salts are liquids which have a sharp taste and which cannot be reduced to the solid state unless some other sort of body is introduced into their composition; they are not sensitive to flame. Such are vinegar, spirit of tartar, acid juices, and all spirits produced from the above mentioned salts.

§113

Salts and spirits of salts are divided into acid, alkaline, and neutral. Acids show themselves by taste, alkaline by effervescence with acids; acids color syrup of violets red, alkalies, green. Neutral salts are those which are obtained by mixing acid and alkaline salts.

§114

Sulfurous bodies are those which easily catch fire and then are wholly or in great part consumed; if anything remains, it consists of slag and not ashes. Such are: sulfur, bitumen, resin, fat, oil, spirit, phosphorus.

§115

Sulfur is a solid body, completely inflammable, evolving a sharp acid fume; it is either separated from other minerals by sublimation, or occurs native, otherwise called living sulfur.

§116

Bitumen is a solid, sulfurous body, a fossil; ignited it evolves smoke with soot, and slag remains after burning. Its forms are amber, asphalt, coal, and other bodies of the same nature.

§117

Resin is a combustible body produced from plants naturally or artificially; here belong myrrh, wax, camphor, etc.

§118

Fats are combustible bodies, isolated from animals, which begin to burn only after considerable heating. Here belong butter, meat and fish fats.

§119

Oil is a fatty, combustible body which refuses to mix with water. It is either of natural origin or artificial; the natural oils emanate from the bowels of the earth, such as petroleum, naphtha, etc.; the artificial are obtained by pressing or distillation. Pressing is carried out on plants, chiefly from seeds with the aid of a machine; such is linseed oil. The distilled oils are driven off by strong, moist sublimation and give ethereal or empyreumatic oils. Ethereal oils are those which are distilled from balsam-like plants at temperatures not above the boiling point of water and which retain the odor of the plants themselves; empyreumatic oils are driven off by a much greater fire from plant or animal substances, and have a bitter or unpleasant taste, causing nausea. The first type are the ethereal oils, cinnamon oil, oil of cloves, etc.; the second are pitch, distilled oil of cream of tartar, oil of hartshorn, etc.

§120

A spirit is a liquid, combustible body which easily takes up water into its composition. Its form differs according to the nature of the fermented body from which it is produced: spirit of wine, grain, etc.

§121

Phosphorus or pyrophors are bodies which spontaneously inflame in the open air with a strong flame, and emit light in the dark, especially if shaken.

§122

By juices we mean bodies isolated from animals or plants which are diluted by water and break up in it, and which, when brought into the solid state, can burn. Their forms are: honey, gums, extracts, decoctions, gelatin, expressed juices, and syrups, for juices are liquids or solidified substances.

§123

Honey is generally well known and does not have varieties except those of different degrees of purity. The types of gum are different, corresponding to the different properties of the plants from which they are extracted. Extracts are obtained from plants by boiling in water and are thickened by evaporation. Decoctions and gelatin are produced in the same way, but from animals. Expressed juices are the juices of plants, especially berries; they become syrups when thickened on a slow fire, forming a honey-like mass.

§124

Metals are solid bodies, ductile, lustrous; they are precious and nonprecious.

§125

Precious metals do not lose their metallic form in a strong fire without addition of corrosive bodies; nonprecious ones by a single ignition fall into ashes and pass over into a glass. The first type are gold and silver; the others are copper, iron, lead, and tin.

§126

Semimetals differ from metals by the fact that they are not ductile; there are five of them: quicksilver, bismuth, zinc, arsenic, and regulus of antimony.

§127

Earths are solid bodies, crumbling or powdery, which can be kneaded with water and give a paste; on dilution with water they form a cloudy liquid from which a sediment separates out on the bottom of the vessel.

§128

Stones are firm, solid bodies which do not dissolve in water and do not soften into a paste.

§129

The forms and types of earths and stones are very numerous, and we can better become acquainted with them from natural

history and by direct study than from descriptions; and we will study their general and specific signs in discussing chemistry.

CHAPTER 6. ON THE CHEMICAL LABORATORY AND VESSELS

§130

Besides the problems of the laboratory itself, we must briefly describe what is required for carrying out chemical operations, namely 1) furnaces, 2) vessels, 3) instruments, 4) materials.

§131

A laboratory should be: 1) sufficiently spacious, divided into several rooms with cupboards so that there can be free space to carry out all the operations and keep the chemical vessels in a suitable place; 2) safe with respect to fires and therefore constructed of bricks or of stone, and arched; 3) supplied with large flues to assure easy outgo of harmful smokes and evaporations.

§132

The Academy laboratory, built by the generosity of the Sovereign in 1748 in the botanical garden under my direction, was constructed of brick as shown in the plan.[2] AAAA is the laboratory itself, B the chamber for weighing materials, separating them, etc.; C another chamber prepared for keeping the vessels which are not always in use; DDDD four pillars for supporting the fume flues of the laboratory; EEEE the bases for the furnaces; F the furnace for heating room B in the winter; GGGG places for keeping materials, raw or produced by chemistry; HHH, cupboards for vessels which should be at hand in the laboratory; K staircase leading to an attic where the supply of chemical vessels is kept.

§133

A laboratory intended most of all for discovering physical truth through chemistry requires no greater number of furnaces than are sufficient for the more common operations and

2. [The plan has not been preserved.]

does not exceed the size needed in using sufficient materials for running experiments: for these labors are undertaken not to obtain profit, but for the sake of science. A chemist cannot be sufficiently careful if he carries out experiments with amounts exceeding those which can be required for developing his mind.

§134

In our laboratory there are nine furnaces, which are enough for us, and these are: 1) *ll,* smelting furnace; 2) *mm,* assay furnace; 3) *nn,* second smelting furnace; 4) *oo,* distilling furnace; 5) *pp,* furnace with a strong blower; 6) *qq,* enamel furnace; 7) *rr,* combustion furnace; 8) *ss,* furnace for glass; 9) *tttt,* furnace for digestion or athanor with bath. Besides these furnaces there can be a portable furnace if it is needed.

§135

We took care to construct two smelting furnaces *ll* and *nn* of the same size because of their many daily uses, for all chemical operations carried out by fire can be conveniently carried out in them if necessity requires. In these furnaces we always carried out fusions, calcinations, preparations, temperings, digestions, amalgamations, cementations, reductions, detonations, and cremations.

§136

The assaying furnace *mm* was constructed with an internal furnace surrounded by charcoal whose opening was seen through the outer wall and was closed by a movable iron door. The outer wall of the furnace was made of thick iron plates and was covered with fire resistant clay. The inner furnace for ceramic work was of a fire of resistant fatty earth and was supported by iron rods covered with clay. Besides cuppelation, for which this type of furnace is especially designed, it can very suitably be used for all operations in which heat alone is required, without flame (§39), and the corresponding effects can be found.

§137

The distilling furnace had two outlets: through one the retort was inserted, after which it was closed with bricks so

that only the neck of the retort jutted out, to which the receiver was fastened. The rear opening served for packing in the charcoal. This furnace, besides distillation, was suitable for carrying out various experiments of vitrification with the help of a charcoal fire, where the vessels with the mixture were strengthened with clay on an open tripod.

CHAPTER 9. ON METHODS OF EXPOUNDING PHYSICAL CHEMISTRY[3]

§

It has been briefly explained in the foregoing what chemistry itself is (this has been done so that in beginning to study mixed bodies we will have in mind the picture of their general properties, their important types, media, and methods of treatment and other matters concerned here and partly shown in tables) and now we come to that which must be brought into chemistry from physics and which can be joined to it so that both sciences, mutually helpful, can aid in obtaining greater development, and on each may be cast a fuller light.

§

After an acquaintance with mixed bodies by the help of chemical operations, the chemist is usually provided with knowledge of the constituents of the bodies and seeks no other path into the secrets of these bodies, but physics, armed with the laws of mathematics, shows a multitude of such paths. Particular properties, as we have shown (§8), originate from mixtures, and chemists are usually absorbed in those which create new individual qualities in bodies by changing the mixed bodies. Since chemical operations are studied just on mixtures, then the mind does not have to pass beyond the qualities and their study where a clear understanding of substances is required; but it is absurd to investigate the reasons of substances when we are insufficiently acquainted with the substances themselves. Therefore it is necessary to know clearly

3. [Chapters 7 and 8 are missing in the manuscript and the paragraphs in Chapter 9 are not numbered.]

the individual qualities of each mixed body which is studied chemically, and as far as possible to determine and note them clearly, so that when the constituent parts are known by these operations, we can find how much and in what form a given quality is changed from a change in the known constituent part and so that from the mutual interrelations of one and the other we can explain the nature of one and the true reason for the other.

§

Among the particular qualities the first is one which appears differently in each body: the specific gravity. Most well-known physicists have already given sufficiently exact determinations of this; but up to now many bodies still remain which have not undergone hydrostatic weighing, but which, however, still merit preference over others already weighed. Then too, in some weighed bodies there remains doubt as to their purity, and some have not been reliably observed. Therefore, everything which is met in this course, mixed bodies and their constituents, everything which can be put into a vessel and touched with the hand should be weighed hydrostatically, and we should carefully note all the circumstances and combinations in each operation to which the body will be submitted.

§

After the specific gravity comes the cohesion of parts of which the mixed body is composed. This, it is true, has been studied for some bodies, especially the ductile ones, by hanging on of weights. But some differences in degree of heat produce changes in cohesion of particles, as can be seen perfectly clearly by the melting of solid bodies and from following our experiments: therefore the previous experiments are not free from some deficiencies. Besides, the time has not been noted which passes between loading on the successive weights and the moment of breaking, and this would be very important to note, since if the application of successive weights is greater than is required, then the wire immediately breaks, and if it is less, then the wire is successively thinned out and then is broken. What objects and what instruments we devise for more exact determination than up to now of the cohesion be-

tween particles of a mixed body of any type will be seen in the following chapter.

§

The different degrees of heat which a body can take up, according to its nature . . .

An Attempt at Physical Chemistry. Part First. Empirical.

The "Introduction to the True Physical Chemistry" was in the main devoted to the general part of Lomonosov's course in chemistry. Some fragments of his approach to the laboratory work have also survived. The selection which follows was written early in 1754 and was first mentioned in the protocol of the Academy of Sciences of April 15, 1754. It shows how Lomonosov planned a study of the physicochemical properties of salts. It was first published in *Collected Works,* II (1951), pp. 579-593.

CHAPTER 1. CONTENT OF EXPERIMENTS AND OBSERVATIONS ON SOLUTIONS OF SALTS

§1

Solutions of salts are preferably made in water, although other aqueous liquids are not to be completely rejected. Here we will consider only water as a universal solvent of salts. We will use other aqueous liquids only to a slight degree, since their variety is almost endless and their multitudinous variety rather distracts the attention than serves to discover truth.

§2

In using water for solution of salts, physics must consider the following: 1) how much of the most important salts can water dissolve at different degrees of heat; 2) the specific gravity of different solutions; 3) the increase in volume of a brine after solution of a salt; 4) the degree of cold obtained on solution of a salt; 5) the expansion of a brine from the first degree of cold to boiling; 6) at what degree of the thermometer does the boiling of the solution and of the saline liquid occur; 7) the duration of retaining heat by the solution as compared to water; 8) what salts are dissolved and in what amount in saturated solutions; 9) what solutions freeze more rapidly on cooling; 10) whether water deprived of air dissolves salts faster or more slowly; 11) whether water loses the cold acquired from salts

with the same rapidity as that acquired from outside; 12) the cohesion of particles in solution compared to that in water; 13) the refraction of rays of the sun in solution compared to that in water; 14) the rise in capillary tubes of solutions and saline liquids compared with the rise of water; 15) microscopic study of solutions; 16) treatment of solutions in the Papin machine; 17) whether there is any action of electrical force in solutions of salts and saline liquids; 19) solution in a vacuum as compared to solution in air.

§3

The ratio of amount of salt dissolved in water is greatly changed with different degrees of heat. This can easily be seen from the following table.

Name of dissolved salt	Amount of water used in thousandth parts	Amount of dissolved salt in thousandth parts at various degrees of our thermometer						
		0	25	50	75	100	125	150
Potash sulfate								
Niter		163						
Common salt								
Wine vinegar salt								
Ammoniacal sulfur salt								
Ammoniacal niter								
Ammoniacal salt								
Ammoniacal vinegar salt								
Alum		62						
Borax		32						
Fixed alkali								
Volatile alkali								

§4

Concerning the crystallization of salt solutions, we must observe 1) appearance of the crust under the microscope; 2) how it evaporates to formation of a crust; 3) by careful study, the shape of the crystals and measurement of the angles; 4) specific

gravity; 5) crystallization induced by severe cold; 6) whether the crystals from water deprived of air are more solid; 7) whether crystallization can promote the electrical force or hinder it; 8) refraction of light in the crystals; 9) crystallization in the Papin machine.

§5

On deliquescence and solution in vapors we should see: 1) how fast the salt deliquesces; 2) how this effect is weakened compared to §4; 3) whether solution occurs with spirit of wine vapor; 4) what change is produced by solution of the salts in the vapors of hot purest spirit of wine; 5) whether crystals of this type give other electrical sparks.

§6

In liquefaction of salts: 1) what degree of heat is required; 2) it is necessary to observe under the microscope the splitting of rock salt; 3) melting in the Papin machine; 4) to note under the microscope the shape of the salt in fractures, solidifying after melting; 5) the hardness compared with the crystals.

§7

Calcined salts: 1) look at the powder under the microscope; 2) specific gravity of the powder; 3) their deliquescence and solution in the vapors with cohobation; 4) increase and decrease in air; 5) increase and decrease in open air; 5) whether they glow under the pestle and what color; 6) what part of the particles is most easily calcined; 7) what is removed from the particles by water, by spirit of wine, by acids and alkalis.

§8

Vitrification of fine powders and salts: 1) alone; 2) with sand; 3) what heat; 4) what cohesion; 5) what refraction of the resulting glass; 6) vitrification by a burning glass; 7) what is the specific gravity; 8) electricity and luminescence.

§9

Precipitation: 1) by fixed alkali; 2) by volatile alkali; 3) at rest or in motion; 4) heat or cold; 4) measure of air produced or absorbed; 5) different dilutions of precipitated and precipi-

tater; 6) difference and the same degree of one and the other and their changes; 7) measure of the precipitated powder; 8) crystals from the complex liquid and their study as above; No. 4; 9) study of the calx under the microscope; 10) specific gravity; 11) color; 12) taste; 13) vitrification; 14) flash under the pestle; 15) whether the electric force hastens precipitation; 16) electrified precipitate, nonelectrified precipitate; 17) precipitation of volatile vapors; 18) mineral growth; 19) mineral growth in a glass tube; 20) in a vacuum; 21) calcination of the precipitated powder; 22) in a hermetically sealed vessel; 23) vitrification of the powder in a closed vessel lacking air and equipped for preventing increase in weight; 24) weight of metal reduced from the powder; 25) cupellation; 26) reverberation of the powder.

§10

Sublimation: 1) generation or absorption of air; 2) quantity separated; 3) specific gravity; 4) value of extension from boiling water to freezing point; 5) difference in extension from freezing to boiling of the same liquid; 6) refraction of the liquid; 7) cohesion; 8) comparative duration of heat; 9) rise in capillary tube; 10) how the electric force affects sublimation; 11) in a vacuum; 12) calcined tartar.

BOOK SECOND. PHYSICOCHEMICAL EXAMINATION OF SALTS

§11

Sulfur and bitumen dissolved in linseed oil, in animal oil, in spirit of wine: 1) cohesion of bitumen; 2) cohesion of solution and solvent; 3) specific gravity; 4) solution at different degrees of heat; 5) increase in volume; 6) change in color; 7) taste; 8) whether on solution heat or cold are produced; 9) how great is the expansion from the boiling of water to the first freezing; 10) its own boiling and freezing points; 11) refraction; 12) rise in capillary tube; 13) treatment of the solution in a Papin machine; 14) how the electric force acts on the solution of salts; 15) color of the electric spark; 16) comparison of the solutions in a vacuum and in air; 17) whether the solu-

tions are different in solvents deprived of air from those pro duced in the presence of air.

§12

Coagulation of the solutions: 1) amount of moisture re moved; 2) cohesion of the coagulate; 3) color; 4) taste.

Meditations on the Cause of Heat and Cold

This paper, which contains some of the most fundamental ideas of Lomonosov and which he himself cited most often in his later works, was apparently written in 1743-44 and was presented at a session of the Academy of Sciences on December 7, 1744. Copies were sent by Lomonosov to Leonhard Euler and other of his friends in western Europe. Along with a group of his other papers, it was finally published in 1750, appearing in the *Novi Commentarii Academiae scientiarum imperialis Petropolitanae,* 1:206-229 (1750), under the title "Meditationes de caloris et frigoris causa." It was abstracted or reviewed in a number of learned journals of the West at the time of its publication. A Russian translation appeared in 1828, and B. N. Menshutkin published excerpts from it in German in the Ostwald *Klassiker,* no. 178 (1910). For a long time this was the only work of Lomonosov which was fairly well known and available to Western scholars. Thus it became accepted as representing Lomonosov's entire corpuscular theory; and only recently have more balanced judgments been possible.

The full Latin text with Russian translation is given in the *Collected Works,* II (1951), pp. 7-55, and the Russian translation is printed in *Selected Works,* pp. 58-80.

§1

It is very well known that heat[1] is excited by motion: hands are warmed by rubbing together, wood is ignited into flame; with a blow to the flint sparks appear from the flintstone; iron glows by hammering pieces and by strong blows, and if these are stopped, the heat decreases and the fire which was produced is gradually extinguished. Moreover, in absorbing heat a body is either converted into insensible particles and is scattered into the air, or it falls into ashes, or the force of cohesion in it is so lessened that it melts. Finally, the generation of bodies, life, growth, fermentation, decay are hastened by heat, slowed by cold. From all this it is perfectly evident that *a sufficient*

1. By such a name we mean also the greater intensity of its force, usually called fire.

basis for heat is found in motion. And, since motion cannot occur without material, therefore it is necessary that *a sufficient basis for heat is found in motion of some material.*

§2

Although for the most part no motion in hot bodies is apparent to the sight, yet this very often manifests itself through action. Thus, iron, heated almost to glowing seems quiet to the eye, yet one body moved near it melts, another is converted into a vapor, that is, its particles are set in motion and this shows that in them motion of some sort of material is present. Then we cannot deny the existence of motion where we do not see it; who, in fact, will deny that when a strong wind passes through a forest the leaves and branches sway, although when viewed from afar no motion is visible. In the same way as here, due to distance, so also in hot bodies due to the smallness of the particles of moving material, the motion escapes the sight; in both cases the angle of view is so acute that neither the particles themselves falling under this angle nor their motion can be seen. However, we consider that no one, unless he is a believer in occult qualities, will ascribe to heat, the source of so much change, a lack of motion, and hence of a mover.

§3

Since a body can be moved by two motions, *total,* by which the whole body continuously changes its position while the parts remain quiet with respect to each other, and *internal,* which is a shift in the position of the insensible particles of the material, and since with the most rapid total motion often no heat is found, and in the absence of such motion great heat may be found, then it is evident that *heat consists of internal motion of the material.*

§4

In bodies material is of two kinds: *cohering,* namely moving and producing pressure with the whole body, and *flowing,* like a river, through the pores of the first body. It may be asked which of these, brought into motion, produces heat? In order to answer this question it is necessary to consider the main effects observed in hot bodies. It is clear from considering these

that 1) in bodies the heat is greater the more dense is the cohering of their material and vice versa. Thus, looser tow burns with greater flames but gives much less heat than that which burns after denser packing. Straw which under ordinary conditions burns with a light flame is used by the inhabitants of the fertile parts of Russia which lack wood in place of firewood, after they have first fastened it into a thick, compact bundle; when more porous wood is burned, it gives less heat than denser wood, and coal which contains rocky material in its pores produces a stronger heat than wood charcoal which, like a sponge, has empty spaces. Moreover, air of the lower atmosphere, which is denser than air of the higher atmosphere, heats bodies around which it flows more than the latter, as is indicated by very warm valleys surrounded by mountains covered with perpetual ice; 2) denser bodies also contain more cohering material in the same volume than does flowing material. Since it is well known from the laws of mechanics that the amount of motion is the more considerable, the greater the amount of material found in motion, and vice versa, then if a sufficient basis for heat consisted in the internal motion of the flowing material, the more rarefied body in whose pores was a greater supply of flowing material should have a greater capacity for heat than denser bodies. However, since on the contrary the amount of heat rather corresponds to the amount of cohering material of the body, therefore it is evident that *a sufficient cause for heat consists in the internal motion of the cohering material of the body.*

§5

This truth is confirmed by the action of celestial fire directed on a body by a burning glass: on its removal from the focus this fire remains in it longer the denser it is, so that in the most rarefied of bodies, air, it does not last for the shortest perceptible time. Hence we add that heat is different according to the differing heaviness and hardness of the body, and experiment shows that its intensity is proportional to the weight of the body, corresponding to the degree of cohesion of its particles, evidently an indication that the cohering material of the body is the material of its heat. Although the cohering material is of two kinds: the natural material of which the body con-

sists and the foreign material lodged in the empty spaces where there is no natural material, yet since both move together with the body itself and are combined in one common mass, it cannot be that when the natural material is aroused to calorific motion there is not the same motion of the foreign material, and vice versa, as on heating a sponge the colder water in the pores receives heat and, reversibly, warmer water heats the colder sponge.

§6

We consider that the internal motion certainly occurs in three ways: 1) if insensible particles continuously change places, or 2) if they rotate while remaining in place, or 3) if they continuously move backward and forward in an insensible space and in an insensible period of time. The first we consider as *progressive,* the second as *rotary,* and the third as *oscillatory* internal motion. Now we must consider which of these motions produces heat. In order to explain this, we take as a basis the following positions. *1) Internal motion is not the cause of heat if it cannot be shown to be in a hot body. 2) Nor is internal motion the cause of heat when it occurs in a body less hot than another body which lacks this motion.*

§7

The particles of a liquid body are bound to each other so weakly that they spread out if they are not held by any solid body and they need hardly any external force to counteract their cohesion, but they can spontaneously separate, withdraw from each other, and move progressively. Therefore we cannot impress permanent marks on a liquid, for these would all immediately vanish. Whether or not internal progressive motion is present in each liquid body, even one colder than the level of vital heat, we will not investigate here; we do not doubt that for our purpose it will be sufficient to show that there are many cases in which it is shown quite clearly. For this we begin first of all with solutions of salt in water. It is invariably found that water felt to be perfectly quiet gives a sensation of cold to the hand when it dissolves sea salt, niter, or sal ammoniac placed on the bottom of the vessel, and distributes them to all its parts. Since this can occur only if the

particles of water remove the molecules of salt which are torn off from the piece of salt, then it is quite evident that the water particles themselves move progressively when they dissolve any kind of salt. In the same way no one can deny this; it happens also in quicksilver when it attacks metals and distributes their particles; in spirit of wine, too, when it removes colored sub stances from plants.

§8

On the other hand, particles of a solid body, especially the more solid inorganic ones, are compounds of such close cohesion that they firmly resist outside forces which tend to separate them; because of this it is impossible to separate them from each other spontaneously by breaking the cohering bonds and to show progressive internal motion. Therefore even the slightest marks on them are retained for centuries and are destroyed only by constant use or by the action of air or by change of the body itself into the liquid state. In this respect a good example is gold which, deposited on the surface of a silver object, remains on it for a long time and wears off only by frequent use. On the other hand it immediately leaves the surface and is distributed through the whole mass of silver when the gilded silver object is melted on the fire. All this clearly shows that the particles of the solid body, especially the harder and inorganic ones, do not have progressive motion.

§9

Having established this, we consider first any silver vessel or other object of this metal covered with gold and carved with the finest engraving marks and heated to such a degree of heat as that of boiling water. We see that the gold on the surface remains unaffected and the marks are not in the least changed; the hardness of the vessel remains as before, and this entirely excludes the possibility of separation of insensible particles. This then most clearly shows that the body can be strongly heated without internal progressive motion. Second, we compare any hard stone, for example a diamond, heated to the temperature of melted lead (which the artisans often do, collecting it for polishing, without any harm or change in the precious stone) with water, cooled sufficiently by dissolving a

salt in it, by which it is still more cooled, or with mercury when it attacks silver; the first we find very hot without internal progressive motion, but the water and mercury which have such motion have a very slight degree of heat. This obviously indicates that often bodies which have internal progressive motion are much less hot than those which do not have such motion. Hence by virtue of the idea given above (§6) it follows that *internal progressive motion of cohering material is not the cause of heat.*

§10

From the definition of the internal oscillatory motion (§6), we see clearly that with such motion the particles of the body cannot cohere to each other. Although there is a very small space in which they vibrate yet here the particles will lack mutual contact and in great part this will not appear externally. For perceptible cohesion the particles of the body require continuous reciprocal contact; therefore the particles of the body cannot show any perceptible cohesion if they are agitated by internal oscillatory motion. But since most bodies on heating to redness keep a very strong cohesion of the particles, it is evident that *heat of a body does not occur from internal oscillatory motion of the cohering material* (§6).

§11

Thus, after this, as we have rejected progressive and oscillatory internal motions, it necessarily follows that *heat consists in internal rotary motion* (§6) *of the cohering material* (§4); for it is necessary to ascribe it to some one of the three motions.

§12

Here, however, we can ask the question, whether the particles of a solid body, occurring in continuous and perfect cohesion, can rotate around each other. In order to answer this, it is enough to remember that two pieces of marble with polished surfaces placed in contact move easily with respect to each other; also glass lenses on grinding adhere so firmly to the rapidly rotating form that they cannot be shifted in a line perpendicular to the plane of contact without their breaking. Con-

sidering this, we can plainly imagine that the finest particles of the body can rotate one around the other in spite of the cohesion, the more easily, the less the observed ratio of their plane of contact to the whole surface. As to liquids, it is quite evident that their particles, which in most cases move by internal progressive motion due to the absence of resistance produced by cohesion, can also have a rotary motion while preserving the first type of motion.

§13

From this theory of ours we also draw the following corollaries. 1) The most suitable form of corpuscular material for calorific motion is the spherical, since such particles can mutually touch at only one point and have almost no force of friction with each other. 2) Since each motion when large can increase or decrease, this must also be assumed for calorific motion. But the greater this motion, the more considerable should be its action; hence, on increasing the calorific motion, that is, on more rapid rotation of the particles of cohering material, the heat should be increased, and with slower rotation, decreased. 3) Particles of a hot body rotate faster, of a cold body, more slowly. 4) A hot body should cool on contact with a cold one, since it slows the calorific motion of the particles; on the contrary, a cold body should warm up due to hastening the motion on contact. 5) Thus, when the hand feels heat in any body the particles of the cohering material arouse a more rapid rotation in the hand, and when cold is felt, its rotary motion is slowed.

§14

There is no surer way to truth than the method of mathematics, which confirms the *a priori* ideas by examples and the *a posteriori* ideas by tests. Therefore, in order to develop our theory further, we explain by mathematical examples the most important effects found for fire and heat, and thus confirm the full reality of the ideas given in §11.

§15

Phenomenon 1. On mutual friction of solid bodies, one of them moves on the other and scrapes it; hence it follows that

particles lying on the frictional surface strike each other. Thus [Fig. 1], let body *AB* move on body *CD* from *B* to *A*; the particle *ab* partly strikes its surface *b* on the part *c* of the surface of particle *cd*, so that particle *ab* excites particle *cd* to motion, and on the other hand, particle *cd* by its resisting force excites particle *ab* to reverse motion. Since these enter the composition of a solid body, they cannot leave their places and move progressively; therefore the motion of body *AB* does not stop, and so particle *cd* will move around its center in the direction in which it is pushed by particle *ab*, and particle *ab* around its

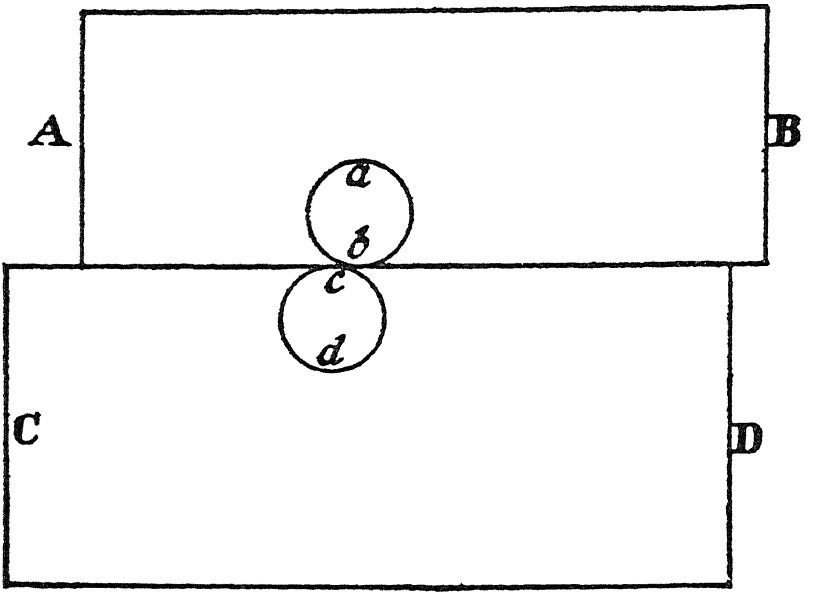


Fig. 1

center in the direction in which it is held back by particle *cd*; that is, both will move in rotatory ways. In this way the individual particles which lie in the plane of friction, being put into rotation, excite the other particles which make up bodies *AB* and *CD* to rotation propagated by friction. Thus it is clear how solid bodies are heated by mutual friction; further conclusions also follow from this. 1) Phenomenon 2. The more strongly the surfaces of bodies *AB* and *CD* are compressed by friction, and the faster they move around each other, the more strongly are particles *ab* and *cd* excited to rotary motion and

the faster the body itself is heated. 2) Phenomenon 3. Since the particles of a liquid body adhere very weakly to each other and very easily leave their places, then when the particles *ab* and *cd* occur on the surface of liquid bodies, they yield place to each other and cannot show that rotary motion which occurs in particles in the composition of solid bodies. Due to all this, liquid bodies not only are not markedly heated by friction between masses of shaken liquids, but also they do not heat solid bodies when their surfaces are wet by liquids.

§16

Phenomenon 4. If we scrape a nail with a longer iron rod, the separate particles on the rod surface strike the particles of the nail which meet them. But since the rubbing surface of the rod is larger than the surface of the nail, then on the nail surface a greater force of particles strikes than on the rod surface; due to this, the particles of the nail, excited by more blows should come to rotary motion faster than the particles which make up the rod. Therefore it is not surprising that the nail is heated before the rod.

§17

Phenomenon 5. When cold iron is hammered with a hammer, especially if it is struck at an oblique angle, then part of the iron mass yields to the blow of the hammer and pushes on the neighboring part which does not feel the blow, and strikes it just like a body closely attached to another surface, and moves it with a strong friction; under the influence of more frequent blows the friction between the excited parts of the iron mass is increased and the rotary motion of the particles is increased so that the iron is sometimes heated to redness. Phenomenon 6. It is just the same in any metallic rod, especially if it is not elastic, when it is repeatedly bent: in fact, parts of the mass on the convex side are pulled apart in opposite directions and, passing by each other, with a rubbing motion they create friction to give a rotary motion and the bent rod is heated.

§18

Phenomenon 7. If a hotter body *A* is in contact with another body *B* which is less hot, then the particles of body *A* at

the point of contact rotate faster than the neighboring particles of body *B* (§13), the faster rotation hastens the rotating motion of the particles of body *B*, that is, gives them part of its motion; as much motion leaves the first as is added to the second, that is, when the particles of body *A* hasten the rotating motion of the particles of body *B*, their own is slowed. Due to this, when body *A* heats body *B* by contact, it itself is cooled.

§19

Phenomenon 8. Further, the particles of body *B* lying on the contact surface when set into motion touch other particles of the same body further from the contact surface; these hasten their motion by mutual friction with the first, and other neighboring ones rotate, and so their internal rotary motion is successively distributed from the plane of contact to the opposite surface. On the other hand, particles of body *A* on the plane of contact are slowed in their motion (§18), and the slowing is transferred from them to their neighbors, then successively to newer and newer particles up to the surface opposite the contact. Hence it is explained why on contact the surface of a less hot body applied to a hotter one is heated before the opposite one is, and the surface of a hotter body applied to a colder one is cooled before the opposite one.

§20

Phenomenon 9. If the opposite surfaces of the less hot body *A* approach two hotter bodies *B* and *C*, then from each contact surface there will be propagated toward the other an internal rotary motion, and therefore it will envelop all of body *A* faster than if this motion, beginning on one side, should be distributed to the other side, that is, if it were supplied either by body *B* or body *C*. In the same way, if body *A* were warmer than bodies *B* and *C* on both sides of it, the rotary motion of its particles should be retarded faster than if body *A* were in contact with the less hot body *B* or *C* alone on one side only. Hence it follows that the rotary motion of the particles is increased or slowed faster, the greater the surface in contact with the hotter or colder body. Therefore, since the surfaces of such bodies are in double and the volumes in triple ratio to the

diameter, then it is also explained why hot bodies of the same nature and the same shape but larger volume in the same surrounding medium, for example air, are cooled more slowly and cold bodies are heated more slowly than if they were of the same volume.

§21

Phenomenon 10. Moving and resting bodies show resistance in proportion to inertia which, as is known, is proportional to the weight; therefore heavier particles are excited by the same force to calorific motion with more difficulty, or if in motion, slow with more difficulty than lighter objects. Hence also it is evident why cold bodies, specifically heavier, in the same resisting medium are heated more slowly and hot bodies in the same cooling medium are cooled more slowly than specifically lighter ones.

§22

Phenomenon 11. It is certain that particles of harder bodies cohere specifically more firmly than particles of softer bodies. Hence the further conclusion is relevant that these are held to each other by greater contact surfaces. Correspondingly, as can be assumed from further consideration, the contact surfaces of the particles themselves should be larger, that is, the particles of harder bodies should have a greater mass than the particles of softer bodies. It happens that particles of harder bodies are in great part rough to the touch and thus give the senses a feeling of their greater size. Since, therefore, with other conditions equal a body of greater volume can be excited to motion with more difficulty from rest, and be slowed with more difficulty in stopping motion than a body of lesser volume, then the larger particles of harder bodies do not receive and give off caloric motion as easily as the finer particles of softer bodies. Thus the reason is clear why harder bodies receive and give up heat more slowly than do softer bodies.

§23

Phenomenon 12. Since particles of a heated body rotate, we must accept the reasoning that by the movement of their surfaces they act on each other so that each repels the other the

more strongly the more energetic is the rotary motion. Since this repulsion opposes the cohesion of the particles, one lessens the other, and on increase of the rotary motion there should be a decrease in cohesion of the particles. Therefore it is not at all surprising that the hardness of hard bodies is decreased by the force of heat and even is finally so weakened that it totally destroys the cohesion of the particles, and we find that first the body is converted into a liquid and then the body is dispersed in the form of a vapor.

§24

Hence it follows 1) that the reason for liquidity and fluidity is the rotary motion of the particles, and the repulsive force thus produced is sufficient to destroy the cohesion of the particles to such an extent that the particles either circle freely around each other and spread out, or by complete destruction of the bonds are dispersed in air. 2) The reason for volatilization and evaporation is chiefly this, that due to different composition of the air, and also to the fact that the calorific, or what is the same thing, centrifugal force acts with differing strength on them, the particles of the body are torn off and scattered. 3) Fluid and liquid bodies always contain heat, though not much, when they seem to be cold.

§25

Phenomenon 13. Body *A* acting on body *B* cannot give to the latter a greater rate of motion than it has itself. Therefore if body *B* is cold and is immersed in a hot fluid body *A*, then the heat of motion of the particles of body *A* excites the particles of body *B* to heat of motion; but in the particles of body *B* there cannot be excited a more rapid motion than exists in the particles of body *A* and therefore the cold body *B* immersed in body *A* evidently cannot show a greater degree of heat than *A* possesses. Phenomenon 14. Hence it is clear why the bottom of a tin vessel filled with water resists heating by a very strong flame which otherwise would easily melt this metal. Actually, although the flame sets the tin particles in very rapid motion, yet the water above it cannot acquire that rate of heat motion which is needed to negate the cohesion of the

tiny particles; therefore the water slows their rotary motion and does not permit the metal to melt.

§26

Here is also the place to mention the reason for the expansion of bodies which is usually increased or decreased depending on their heat. Since expansion does not occur directly from the heat, but from the elasticity of the air included in the pores of the body, we will leave this effect to be considered at another time. Moreover, we cannot designate such a great rate of motion that there cannot conceivably be a still greater one. This relates properly to calorific motion; therefore it is impossible for a highest and final degree of heat to be due to motion. On the contrary, it is true this same motion can be so decreased that a body finally reaches a state of rest, and no further decrease in motion is possible. Hence, from necessity there must exist a greatest and final degree of cold which should consist in absolute rest from rotary motion of the particles.

§27

Although a greatest degree of cold is possible, yet there is no evidence which indicates that such a state occurs on the terrestrial sphere. Actually, everything which seems cold to us is only less hot than our organs which feel it. Thus, the coldest water is still hot, since ice, into which water freezes with a very strong frost is colder than it, that is, less hot. If melting wax is actually hot, then why is water which seems to us very cold, in actual fact not hot, for it is nothing else than melted ice. However, we should not conclude that freezing of a body is a sign of the greatest cold, for metals which solidify immediately after melting are of the nature of ice, but they are so hot that they ignite a hot body which approaches them. However, there are liquid bodies which do not freeze at any known degree of cold. Since their liquid state depends on calorific motion (§24), it is clear that these liquid bodies always have some degree of heat. Further, bodies usually have a degree of heat inherent in the medium in which they have been immersed for a considerable time. And since air, found always and everywhere, is a fluid, that is, as demonstrated, warm, then all bodies surrounded by the earth's atmosphere, even though seeming cold

to the senses, are warm; and therefore the highest degree of cold does not exist on our terrestrial sphere.

§28

Thus we have shown *a priori* and confirmed *a posteriori* that the cause of heat is internal rotary motion of cohering materials; now we pass to a consideration of ideas which the majority of contemporary scholars have expressed concerning heat. In our times the cause of heat is ascribed to a peculiar material which most call caloric, others ether, and some, elementary fire. They say that a greater amount of it occurs in a body in which a greater degree of heat is observed, so that at various degrees of heat of a given body the amount of calorific material in it is increased or decreased. Although it is sometimes assumed that the heat of a body is increased by strong motion of this material entering it, yet most often they consider the true cause of increase or decrease of heat to be a simple entry or departure of different amounts of it. This idea has taken such a deep root in the minds of many and is so strong, that everywhere we read in physical papers of the entry into the pores of a body of the above mentioned calorific material as if some sort of love potion were attracting, or, on the other hand, a violent departure from the pores as if it were seized with fright; therefore we consider it our duty to submit this hypothesis to a test. Most of all we must answer the actual originators from whom this idea came. There are four of them who are most important, to whom we should look for an explanation of other effects of nature.

§29

When scholars began to study more attentively the effects connected with the heating of bodies, they easily noted that on increase of heat the volume of each body also increased. Since they knew exactly that nothing except heat had been added to the body, and their minds still held strongly to the ancient idea of elementary fire, they did not hesitate to conclude that on calcination some sort of material, native fire, entered the pores of the body and expanded it; and when it left it, this body cooled and contracted. We would agree with them willingly if they could as easily show just how the heat

material is driven into suddenly heated bodies. How, I ask, in the coldest winter when everything is enveloped by severe frost, or in the coldest depths of the sea[2] where, according to this hypothesis there is almost no heat material, gunpowder, ignited by the smallest external generating spark, suddenly expands with a great flame? Whence and by what remarkable virtue are fire and this material instantaneously brought together? But let it fly however impetuously in coming from a most distant place, what would be the reason for the ignition and expansion of the gunpowder? In this case it would be necessary either that another body surrounding the gunpowder was previously heated by arriving fire and was expanded, or that this volatile fire, nothing else than the gunpowder itself, could not ignite and expand, which would be for it to forget its own nature; the first is evidently contradicted by experiment, the second by common sense.

§30

In general the nature of a thing is such that on increase of its source there increases also its action, and on the contrary, when this decreases, its action is lessened. Therefore, when the same degree of heat is observed in two bodies with other conditions equal, there should be the same increase or decrease in the amplitude of each body. But what differences are found in this respect! I say nothing about air which from the degree of freezing of water to the degree of its boiling expands by a third part while water in this time increases by one twenty-sixth part of its volume. Even bodies of almost the same liquidity, such as mercury, water, spirit of wine, different oils, and also some solid bodies like metals, glass, etc., show an evident variation in increase or extension from the same degree of heat. However, let no one assume that more marked cohesion of the parts acts as a hindrance for expansion: for steel has a stronger cohesion of the particles, as everyone knows, but experiment shows that steel expands more, iron less. So also for bronze, a body harder than copper which expands more than the latter from the same degree of heat. We cannot ascribe any slowing in incandescence to the great weight of a body, not to mention

2. Boerhaave, *Elem. Chym.*, part 2, from Sinclair, *Arte gravitatis*, p. 301.

any other fact which in different bodies would hinder their expansion, without showing contradictory cases which run counter to the assumption made when the expansion of heated bodies is ascribed to entering material. But this is the case for different bodies. Sometimes one and the same body is compressed when heat increases; for example, water coming from ice is specifically heavier than it, since even with a considerable degree of heating it does not permit the ice to sink to the bottom. Thus also iron and most other bodies, still in the solid state, float in those same bodies in the fused state, since they occupy a greater volume though they still do not have the same degree of heat at which they usually melt. From all this it is quite clear that expansion by accumulation of heat and contraction on cooling cannot at all show these apparent shiftings of the material of heat.

§31

However, this theory, already weakened by its own magnitude, can be established in another way by a fact which has greater weight. Thus scholars, and especially chemists, think that this circulating fire can show its presence in bodies not only by an increase in their volume, but also by an increase in weight. If I am not mistaken, the most illustrious Robert Boyle showed for the first time in an experiment that bodies increase in weight on calcination[3] and that one could make part of fire and flame stable and ponderable. If this could actually be shown for some elementary fire, then refutation of our opinion would be strongly supported. However, the greater part, almost all, of his experiments on increased weight by the action of fire led to this, that the weight was possessed either by part of the flame calcining the body, or part of the air which during the calcination passed over the calcining body. Thus, metallic plates burned in the flame of burning sulfur actually expanded and increased in weight; but here the reason for the increased weight is nothing else than the acid of sulfur which can be freed from phlogiston, collected and accumulated under a bell; then it penetrates into the pores of copper and silver and, combining with them, produces an increase in weight. Thus when

3. In the Treatise on the Weight of Fire and Flame.

lead is burned to minium, the workman deliberately directs onto the liquefied metal the very smoky flame; it is just this which colors the lead slag red and increases its weight, to the profit of the workman. The remaining experiments of the famous author in a supplement to the paper mentioned seem, it is true, more positive, but they are not at all free from doubt, since the author himself was not present at them and carrying them out was entrusted to some assistant. But let us assume that besides the particles of the calcined body or the particles flying around in the air, which continuously flows around the calcining body, some other kind of material is added to the metal which increases the weight of the calx. Since the calx, removed from the fire, keeps its acquired weight even in the most severe frost and, moreover, does not show any excess heat in itself, then it follows that in the process of calcination some material is added to the body, but not that which is ascribed to the fire itself, for I do not see how the latter in the calx could forget its own nature. Further, the metallic calx reduced to the form of the metal loses its acquired weight. Since the reduction is produced in the same way as the calcination, by an even stronger fire, we cannot find any basis why the same fire introduced into the body by it, then leaves, also by it. Finally, all the similar experiments made by the famous Boerhaave[4] and Duclos[5] evidently had contradictory results. The first investigator weighed, before calcination, and then again after calcination and cooling, five pounds and eight ounces of iron, but did not find any change or decrease in weight. The second worker ascribed increased weight of minerals on calcination to sulfur particles carried in air (as we said above) which continually flowed over the mineral undergoing calcination, and the introduction of the latter when these particles broke up in the fire; he showed this in his experiments: he found that from regulus of antimony burned in open air there was extracted by spirit of wine a red extract, by the removal of which the remaining mass had the same weight as the regulus before burning. 2) Regulus of antimony burned in another way, namely, without increase in weight, does not give

4. *Elementa Chymiae,* part 2, *De Igne,* experiment 20.
5. *Mem. de l'Acad. Roy. des Sciences,* Année 1667.

such an extract. Thus, the argument is also not conclusive when given in defense of the individuality of fire material based on increased weight of a calcined body.

§32

The rays of the sun, caught and collected by a burning glass, give a very strong heat and a bright light; it is thought that this shows visually and with the sun itself as a witness that heat material or elementary fire coming from the sun is condensed at the focus and this strengthens the brilliance and heat. It is easy to see here that it is assumed that the material of light is emitted from the sun like a river from its source. This hypothesis is very much as if we should state that air from a sounding body is emitted on all sides at a rate equal to the speed of sound. Evidently ether and light, which differ from each other in the same way as motion and matter differ from each other, are here confused, and it is clear that we should discard the condensation of material delivered to the focus of the glass and replace it by concentration of heat motion. For me, the assertion that in the focus of the burning glass or mirror there is concentrated the matter of ether does not seem otherwise than if we should say that in the focus of an elliptical arch sound waves are not collected, but the material of air itself is concentrated. That the sun's focus is very hot is not due to the great density of ether matter, but is due to its heat motion; this is sufficiently shown by the focus of the sun's rays reflected from the moon. Since they are very bright, they should also be very hot if the heat came from a concentration of ethereal matter. But there is no heat in them; therefore the luminous focus is produced either by accumulation of ether matter or by concentrating its motion. To exclude concentration of material means to go against the hypothesis; to avoid concentration of motion means to recognize that fire matter can also exist in the cold, that is, that fire is not fire. Whoever considers this without prejudice then will agree with me that the existence of heat material can in no way be shown from the occurrence of heat in the focus of a burning apparatus.

§33

By mixing common salt with snow or crushed ice, physicists obtain a substance called from its origin a freezer, since water

placed in it in some sort of a vessel is converted to ice. While this is taking place, the snow with the salt melts. Hence it is usually concluded that fire matter from the water moves into the surrounding snow and from combination with it the latter melts, and the water, because of the departure of fire matter, is converted to ice. Beautiful! But something remains to be tested before our trophies of victory are snatched away. Introduce, if you please, a thermometer and a bottle of water into the snow, add salt to the snow, and you will see that while the water is converted into ice and the cooling mixture melts, the alcohol in the thermometer still sinks; a clear sign that along with the freezing of the water the cooling mixture becomes colder; thus no elementary fire is forced into it from the water, but rather the snow, melted by contact with the warmer water, acts on the salt, dissolves it, is cooled, and acquires a less degree of heat than the water has as it passes into ice. From this the pure water in the vessel freezes and the snow itself, due to the absorption of the salt, remains liquid. Who, in fact, does not know that pure water put in a glass vessel in water saturated with salt is converted into ice at 26° on the Fahrenheit thermometer, while the brine itself remains liquid?

§34

On the basis of all the above ideas we state that we cannot ascribe the heat of a body to condensation of any sort of subtle material especially assumed for the purpose, but that heat consists in internal rotary motion of cohering material of the heated body; and we not only say that such motion and the heat of the most specific and finest matter of ether, which fills all space, do not contain sensible bodies, but also assert that the matter of ether can communicate the motion of heat obtained from the sun to our earth and the other bodies of the world and to heat them; it is the medium by which bodies separated from each other communicate heat without any direct sensible ones.

§35

Rejecting the material which other authors have assumed as the exclusive cause for explaining heat, we could conclude if,

on the other hand, a new problem did not arise. This is that the cause of cold is also a peculiar substance, seeing that there can be a positive basis for this in salts, due to the production of cold in their solutions. But since the same salts sometimes also produce heat, and thus ordinary salt effervesces and grows hot when oil of vitriol is added, we could with the same reason ascribe a principle of heat to the salt if we did not consider such an unintelligent controversy beneath our contempt.

Dissertation on the Action of Chemical Solvents in General

During the years immediately after his return from Germany to St. Petersburg, Lomonosov developed most of his chemical ideas and embodied them in a series of papers which he presented to the Academy of Sciences. These were finally collected and published in 1750. The following paper was written in 1743 and revised several times before reaching its final form in 1745. It is the first paper to include a description of actual experiments carried out by Lomonosov before the construction of his laboratory in 1748.

The paper was read and approved by Euler in 1747, and was published in the *Novi Commentarii Academiae scientiarium imperialis Petropolitanae,* 1: 245-266 (1750) in Latin with the title "Dissertatio de actione menstruorum chymicorum in genere." The Latin text and Russian translation were published in *Collected Works,* I (1950), pp. 337-383, and the Russian translation appeared in *Selected Works,* pp. 19-42.

§1

Although even in ancient times persons skilled in chemistry devoted much work and effort to the science, and especially in the last hundred years its supporters strove with each other, as we might say, to study the composition of natural mixed bodies, yet one important part of natural science was still hidden in deep darkness and was smothered by its own mass. The true reasons for the astonishing effects which nature produces by its chemical actions were hidden from us, and therefore, up to now, we have not known of a more direct path leading to many discoveries which would increase the happiness of the human race. For we must recognize that although there are a great multitude of chemical experiments whose accuracy we do not doubt, yet we can rightly complain that we can draw from them only a small number of conclusions such as would please a mind satisfied only by geometrical demonstrations.

Action of Chemical Solvents in General

§2

Among the most important chemical operations is solution of bodies, which most of all deserves physical investigation: in fact, it is very often used in chemical laboratories in the study of bodies, and in lectures in physics it is usually shown to the curious along with other experiments; however, the causes of it are still not clear enough for an explanation of the effects which occur in this operation.

§3

Usually those who speak of the causes of solution assert that every solvent enters into the pores of the dissolving body (it will be shown below that this does not always occur) and gradually breaks the particles. But as to the question of what force carries out this disruptive action, no sort of probable explanation is given except the arbitrary ascription to the solvent of wedges, hooks, and I do not know what other instruments.

§4

The same solvent cannot act on every kind of body, but for the solution of each body there will be a corresponding solvent. The usual explanation for this is to assume differences in the size and shape of the pores of the dissolving body and the particles of the solvent, so that, as it is assumed, the pores are blocked up or access is made easy for the solvent which enters them. Thus, for example, while spirit of niter dissolves silver, copper, iron, and other less precious metals, it does not act on gold, and this is usually explained by the statement that the pores of gold, as the densest of all bodies, are the narrowest and therefore the particles of the spirit of niter cannot enter them. We are prepared to recognize that larger particles of solvent cannot penetrate into finer pores of the dissolving substance, but as we will see later, particles of spirit of niter are much finer than pores of gold. Spirit of niter and spirit of salt taken separately do not dissolve gold but, mixed into aqua regia, they become a special solvent for gold. Hence they enter its pores (that this actually occurs will be shown in §20), whence it follows that particles of spirits of niter and salt combined in mixed corpuscles are smaller than the pores of gold and hence have much less diameter than pores of gold. How-

ever, there is no doubt that there are many who assert that spirit of niter is subtilized by salt, that is, its particles are made smaller. But if this were actually so, then spirit of niter, carefully separated from spirit of salt, since it had been made finer, would dissolve gold in this state alone, which does not happen at all.

§5

There are also other reports which indicate that large diameters of pores do not facilitate entry of liquids into solid bodies at all. Thus, mercury easily passes into the pores of gold, a very dense body, but does not penetrate into wood, leather, and paper, which are very porous bodies, unless force is used.

§6

Neither can we find much to hope for with different forms of pores or particular shapes in order to explain the reasons for differing penetrations of solvents into bodies. Actually, if the qualities of a particular body depend on this, then a great disparity of shape should exist between the particles of mercury and aqua fortis; for these two bodies differ in many qualities: ability to pass and reflect light rays, taste, density, and differing abilities to act on homogeneous bodies. Nevertheless, both these solvents pass into the same pores of the same body, namely, silver. That the shape of a body impedes very little its entrance into a sufficiently wide passage is also evident without scientific study: we can see that people, pack horses, and wagons, in spite of their different shapes, pass through a wide gate.

§7

The entry of a liquid into the pores of a solid body is nothing more than the combination of both bodies into one, like the mixing of liquid bodies. The difference lies only in this, that when two liquid bodies are mixed, they both penetrate into each others pores by internal progressive motion, and when a liquid body combines with a solid, only the liquid body enters the pores of the solid by internal progressive motion.

§8

When liquids are blended, one mixes more easily, another

with more difficulty: thus water easily mixes with aqueous spirits such as acid or ardent spirits, but does not give combination with oils; in the same way also for fused solid bodies: metallic bodies combine much more easily with metals, earthy bodies with earths, salts with salts than do metallic bodies with earths or rocks or fused salts. Hence it is clear that the particles of liquid bodies of the same type penetrate each other more easily and more readily enter the pores by progressive motion than do particles of different types of liquid bodies.

§9

Thus, as a measure of the similarity of type, we should determine the entry of liquids into the pores of solid bodies (§7), that is, liquids should more easily penetrate the pores of similar solid bodies, and with more difficulty the pores of different sorts. This is confirmed by the following experiment. On separation of the precious metals from the lower ones in the assaying furnace, the fused lead does not enter the cupel until it vitrifies. This means that up to that time the metal retains inflammable material in itself which imparts luster and ductility to it, and it cannot mix with the ash forming the cupel and penetrate its pores. But when the phlogiston is driven out by force of fire, the other constituent part of the lead remains and this latter, losing ductility and metallic luster, vitrifies and penetrates the pores of the cupel, which is a body also capable of vitrifying; this means similarity of type, and so it is carried into the pores of everything which can undergo vitrification. Therefore it is not surprising that gold and silver do not enter the ash of the cupel, for they never vitrify.

§10

Since similarity of type, which facilitates entry of liquids into solid bodies, consists in identity of the material itself, it is vain to seek it in the pores themselves; the reason why specific solvents easily enter the pores of the dissolving body does not lie in them, for the pores are nothing else than spaces which do not contain the material of the actual body.

§11

Thus, since almost everything which has been proposed up

to now concerning the cause of solution does not have a firm foundation, we feel that it is not useless to create a more exact theory of this cause, considering in more detail the physical and chemical experiments which can supply some sort of explanation for solution, and comparing them with each other. Here, however, we will not give a complete explanation of the separate special properties by virtue of which different solvents act on different dissolving bodies (this cannot be expressed and clarified until the number of chemical principles has been decided and their chemical nature becomes exactly known), but we propose only to describe the reasons for solution in general.

§12

Thus, studying the general causes for solution, we will attempt to show how and by what forces solvents can separate the particles of the dissolving substance, nullifying the internal cohesion. The acting particles of the solvent and the action itself are not evident to the senses; it therefore remains for us to attempt to find the truth by centering all attention on the effects alone which accompany solution.

§13

Comparing these effects with each other, we find that in one case they are the same, and in another contradictory. The best known such cases are: acid spirits are heated in the solution of metals, but water is cooled in the solution of salts. These effects depend on opposite causes, so that we suspect that metals are dissolved in acid spirits differently than are salts in water. Since experiments on solution in a vacuum which we have carried out have shown full agreement with the theory which we had previously worked out, we have strengthened it by these experiments so that now they are firmly established.

§14

When aqua fortis acts on metals, effervescence is usually produced; in order to observe this I took an iron wire, short and thin, and fastened each end of it with wax to a glass jar; in the middle of the wire I placed a drop of spirit of niter diluted with water so that solution occurred slowly (a rapidly occurring process of this type is too indistinct and difficult to ob-

serve): above the drop which was dissolving the iron I placed a sufficiently strong microscope. Bubbles of air arose from the surface of the wire along with particles of iron of a brown color which, like the air bubbles, were driven off in a direction perpendicular to the iron wire, and though I often changed its position, yet they retained their perpendicular direction. After this, using stronger spirit, I again watched solution of the wire under the microscope. I saw a great mass of particles driven off with countless bubbles continuously following each other; they came from the surface of the wire in a perpendicular direction and appeared in the light of a candle like countless glittering fountains, or rather, like entertaining fireworks shot simultaneously into the air. The particles of iron in the latter case were not seen until, repelled further from the wire, they moved into the solvent with a confused motion.

§15

Thus the particles of metal were repulsed by the strength of the solvent in a direction perpendicular to the surface of

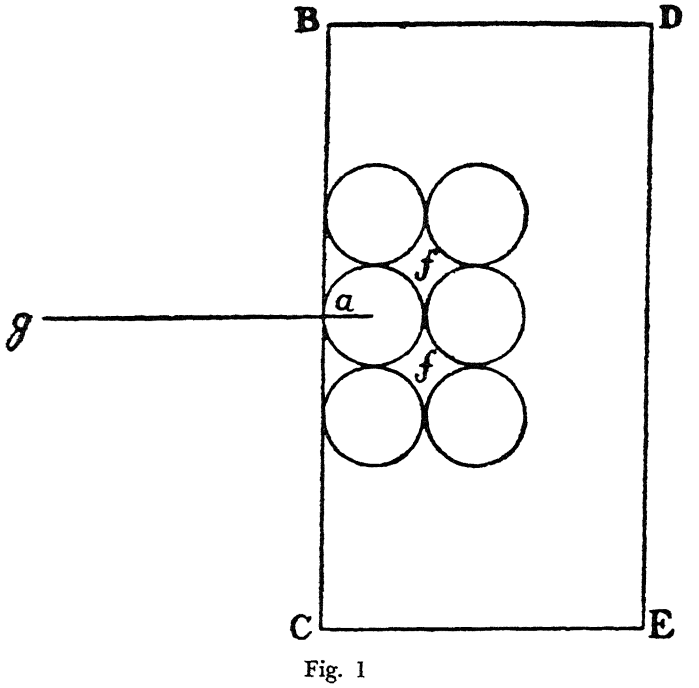


Fig. 1

the dissolving body [Fig. 1]. Let us assume that particles *af* are repulsed by the action of the solvent from the surface *BC* of the body *BCDE* in the direction *ag*; it is therefore necessary that the solvent acted on them in the same direction, that is, pushed them from *a* to *g*; but to push from *a* to *g* it cannot do otherwise than to hit part of the surface of the dissolving body *ff* on the other side from the closest dissolving surface of *BC*; the solvent cannot hit this unless it is first placed between the particles *af* and the other parts of the dissolving body in the spaces *ff*; that is, the acid spirit cannot dissolve the metal except in entering its pores.

§16

Metals fused in a very strong fire effervesce and, like acid spirits and water, throw off bubbles of air, a clear indication that in metals, as in acid spirits and water, air is present, scattered through their pores, and is driven off from them by heat; by virtue of its particular lightness this rises and forms bubbles.

§17

As soon as metals are dipped into acid spirits they at once throw off bubbles of air from their surfaces; hence it is clear that the air, scattered in the pores of each body or one of them expands at the moment of solution, that is, shows the effect of its elasticity. This can occur for three reasons: 1) by removal of the pressure of the outside air; 2) by the air itself taking up a greater degree of heat; 3) finally by introduction of a larger amount of air into the same receptacle.

§18

Since the solution of metals, accompanied by effervescence of the solvent, always occurs under atmospheric pressure, it is quite evident that this expansion of air does not come from the first reason mentioned. Further, acid spirits dissolving metals first effervesce, then are heated, and the heat which follows effervescence is always much less than that which occurs on boiling of acid spirits exposed to fire; therefore the expansion of air which produces effervescence in acid spirits dissolving metals does not depend at all on increased heat. Hence a sufficient reason for the boiling of aqua fortis is found in the compres-

sion of air scattered in the pores of the aqua fortis itself or of the metal.

§19

Thus, we must accept the observed compression of air in the pores of the spirit solvent or of the metal itself. Since the particles of spirit, the liquid body, do not cohere very strongly to each other, they cannot resist the air condensing in their pores and expanding by reason of its great elasticity; therefore they should give way to the rising tension since the air, expanding quietly in bubbles because of its lightness rises without any agitation to the surface of the liquid. But the air bubbles liberated at the time of solution are precipitately repelled perpendicularly to the surface of the metal at any position of the latter (§14); therefore we cannot assume that this air was condensed in the pores of the solvent spirit, and hence it should be in the pores of the solid body, that is of the metal itself, iron, from whose surface it was evolved in small bubbles.

§20

But air cannot be concentrated in the pores of the metal without addition of new air to that already in them; and in the course of solution no air can be added except that entering with the solvent into the pores of the metal, that is, air which occurs in the pores of the solvent. This is confirmed by further results.

§21

Air scattered in the pores of the liquid penetrates the closest and narrowest pores of the solid body into which it cannot go alone. The reason for this can easily be seen from our theory of the elastic force of air (§24 and 26), and this truth, confirmed by experiments made by the illustrious Wolff with the pores of a bladder, is well known to physics.

§22

When the air under the bell of an air pump is exhausted, boiling is produced in acid spirits with much more difficulty than in water; hence it is evident that air is more strongly

fixed in the pores of acid spirits than in the pores of water and that hence this air penetrates the pores of solid bodies with these spirits more easily than with water.

§23

When liquid homogeneous bodies touch each other, they mix together, so that a drop of water adds to itself a second drop nearest to it; two globules of mercury, when they reach sufficient contact absorb each other at once and form a single globule; therefore there is no doubt that particles of air also along with acid spirit penetrate the pores of the metal and because of the fine separation of the solvent, the liberated particles are combined with the air molecules present between the particles of the metal.

§24

It is easy to see what follows from everything which has been said, if we keep in mind first those properties of air which were discussed earlier[1] and to which we have given the name *regenerated elastic force of air.*

§25

Certainly the natural properties of air are such that its most minute particles, removed from mutual contact, occur as inclusions between the particles of some denser body, and have almost no elasticity, but, liberated from their prison they allow themselves to come into mutual contact and again regain their half-dead elasticity and show it with respect to a resisting body. Very many experiments carried out by the most excellent Hales have shown this most clearly, and we have made many experiments for this purpose, of which the following are most suitable for strengthening the assumptions of our theory. I poured 5 drams of spirit of niter into a vessel with a narrow neck and put into it 2 drams of copper; I immediately tied a bladder tightly to the neck of the vessel, after which as much air as possible was driven out from it; solution stopped after about the fourth hour and the bladder was very much inflated with air evolved from the metal and spirit; tying up the bladder

1. Attempt at a Theory of the Elastic Force of Air, § 26.

over the neck of the vessel with thread, I took it from the vessel and did not doubt that it was full of true air, for after pinching the bladder with the fingers it again assumed its former shape; placed in snow it became limper and on placing it near a furnace it inflated again; pricked with a needle and compressed, it emitted a stream of air which set in motion light objects near it and the flame of a candle. Making a careful measurement, I determined the ratio of the volume of air expanded by regeneration of the elasticity to the volume of spirit and metal as 68 : 1 and to the metal, of which 1 dram was dissolved, as 2312 : 1. From these experiments it is quite evident that air scattered in the pores of the bodies lacks almost all of its elasticity and, on the contrary, after its particles are liberated from the enclosing body and come into mutual contact, their elasticity is again restored.

§26

The elastic property of air regulated in this way has surprising actions. It breaks vessels in which water is converted into ice; iron tubes fly apart with a great noise. Evidently under the influence of cold, water is compressed into less space; its pores are made narrower and air is squeezed out from it, as is indicated by the numerous bubbles which cooled water gives off; the liberated air particles collect together as homogeneous bodies mixed together; they again attain the elasticity inherent in them which was previously lost by separation and expand, forming bubbles, and thus when an innumerable number of particles has collected, forming innumerable bubbles, the water at the moment of transformation into ice expands and breaks the strongest vessel which contains it. The truth of this is shown by the fact that ice removed from the vessel broken by it is filled with innumerable bubbles and lacks almost all transparency.

§27

Considering all this we do not find it difficult to show the actual force which scatters the particles of metal torn off by acid spirit. Particles of air entering with the acid spirit into the pores of the metal on solution combine with those which were previously present in the metal (§21); from this they re-

gain the lost elasticity (§§24, 25, 26), trying to expand into a greater space and not being able to endure the narrow pores, they seek an outlet; and since they are blocked in and locked up by the acid corpuscles which are following them they break off the particles of metal which oppose them and drive these through the spirit. Evidently the particles of acid spirit on solution introduce particles of air into the pores of the metal and the air tears the particles from the metal by its regained elasticity.

§28

For the study and confirmation of this theory I have made the following experiments. I poured into a cylindrical glass vessel 5 drams of aqua fortis and placed it under the bell of an air pump. After several strokes of the piston, air was pumped out and air bubbles began to evolve from the aqua fortis, frequent but small. After the fourth hour I put the solvent out in the open air again and placed in it a copper coin, which we call *denga.* After the first 20 minutes I poured in a large amount of water and cleaned the coin of sediment and adherent moisture; I weighed it and found that it had lost 74 grains. Then I placed a second copper coin, equal and similar to the first, in 5 drams of the same aqua fortis, but from which the air had not been driven off, and I placed it in the same vessel and put it in the same place for solution. After the first 20 minutes the coin was 85 grains lighter. This experiment showed that acid spirit acts on metals more strongly if it contains a larger amount of scattered air and hence each portion of aqua fortis introduces with itself a more considerable amount of air into the pores of the metal; the elasticity rises more rapidly and tears off pieces of metal more often.

§29

Then I took the aqua fortis in the same two identical portions and poured them into two vessels, equal and of the same shape, and at the same instant dropped into each a copper coin which we call a *poluschka,* each one of which weighed 50 grains; one vessel remained in the open air, the other was placed under the bell of an air pump. Both coins at first dissolved with the same effervescence of the solvent. But when

several strokes of the piston had pumped out the air from the bell, the solvent began to boil much more strongly: the bubbles were larger and they were evolved more often than in the previous experiment. At the end of 11 minutes both coins were simultaneously removed from the solvent, freed from sediment and moisture, and weighed. That which was dissolved under the bell lost 10 grains, and that which was dissolved in the open air lost 26 grains. Thus, in this experiment the excess of copper dissolved in the aqua fortis which contained the whole weight of scattered air was relatively much more than in the previous experiment, namely, in the first experiment the ratio was as 11 to 74, in the second as 16 to 10. The explanation of the fact is this. The aqua fortis dissolving the metal under the bell of the air pump was warmed and lost a greater amount of air than in the previous experiment; thus the solvent was deprived of a large amount of the air scattered in it and therefore should act on the metal with less force.

§30

These and other phenomena accompanying the solution of metals fully agree with the proposed theory: most important here is the heat connected with the effervescence of the solvent. The elasticity of air regenerated in the pores of the metal tears off particles of the metal which are carried off through the solvent, causing friction on the particles of the latter and causing them to rotate, and since rotary motion is the cause of heat[2] then it is not surprising that aqua fortis grows hot when dissolving metals.

§31

Spirit of niter with zinc gives a very great effervescence and is strongly heated; with iron, somewhat less so, with copper, less still, much less with silver, very little with lead and mercury. Hence it is evident that metals and semimetals, especially the lighter ones, produce a greater effervescence and heat in spirit of niter than the specifically heavier ones, which fully agrees with our theory. For the physicist does not doubt that metals and semimetals, specifically lighter, consist of a lesser

2. Mediations on the Cause of Heat and Cold, § 11.

amount of coherent material and hence have more or more frequent pores than the specifically heavier material. Therefore they contain a greater amount of scattered air; more air is additionally introduced with the solvent into the pores of the metal, and there is a greater increase in elasticity which acts more strongly on the particles of metal, tearing them off more strongly and leading to more rapid rotary motion of the particles of spirit of niter, markedly increasing the boiling and heating.

§32

If iron is dissolved in alkali and precipitated by vinegar, then spirit of niter dissolves the calx without effervescing. It is just the same on mixing a solution of copper green in distilled vinegar with aqua fortis; the latter takes the copper into itself, but no effervescing occurs. In both cases the particles of metal have no mutual cohesion and hence do not require the same force which in other cases tears them off, but these particles immediately adhere to the added particles of solvent and spread with it by progressive motion. Therefore no accumulation of particles of scattered air occurs, its elasticity is not regenerated, and there is no effervescence or heat.

§33

When we take sufficiently concentrated portions of the same acid spirit for solution of metals, but one of the portions is somewhat diluted by mixing with water, then this dissolves a greater amount of metal than the first, due to the greater amount of air scattered through the large volume.

§34

When a sufficiently strong spirit of niter is used for solution of the metal, solution is completed quickly, since the solvent ceases to act. But if after several days metal is immersed in the same spirit, then again a considerable amount of it is dissolved. Evidently, when violent solution occurs, the spirit becomes somewhat deficient in air so that it can no longer act on the metal; but when in the course of time it receives into its pores aerial particles from the surrounding air, it again acquires the ability to dissolve.

§35

A high degree of confidence is gained in physical problems if a thesis is studied and demonstrated *a priori* and is confirmed by phenomena and experiments so that it is also in agreement with mathematical truth. In order to establish such a degree of validity for this theory, we should show that the elasticity of the air regenerated in the pores of the metal is sufficient to break off its particles.

§36

For this purpose it is necessary first of all to consider what force is required to produce such action, that is, how strong is the mutual cohesion of the particles which the force of the air regenerated in the pores of the metal breaks off from the surface of the latter. The illustrious Musschenbroeck found by experiment that in order to break up a copper wire whose diameter was 1/10 inch of a Rhenish foot divided into 12 equal parts or 1 19/120 of a line of the royal Parisian foot [about 2.6 mm] required a weight of 299¼ Amsterdam pounds, which equals the Parisian one [about 146 kg]. Under the microscope which increased the diameter of the body 360 times, I found the finest particles of copper dissolved in spirit of niter had an apparent diameter of ½ line of the Parisian foot. Therefore the true diameter equalled 1/720 line. We suggest that the wire itself, consisting of such particles arranged beside each other in a continuous series and cohering by strong linkages has a diameter equal to that of the particles themselves. Since the force required for breaking a homogeneous body is double the diameter of the body itself, therefore the force required for breaking this finest fiber is related to the weight of 299¼ pounds as the square of the diameter of the same wire to the square of the diameter of the wire broken by a load of 299¼ pounds, that is, $= (1/720)^2 : (1\ 19/120)^2 = (1/720)^2 : (834/720)^2 = 1 : 695\ 556$; hence it equals 1197/2 782 224 pounds or 3 846 288/2 782 224 grains. This force equals the force of cohesion of the particles of copper broken off by the elasticity of the air which is regenerated in the pores of the metal.

§37

Whoever finds air massively evolved from the metal at the time of solution can easily admit that it occupies the greater

part of the bladder tied to the neck of the vessel (§25). It is true that we do not deny that the bubbles arising from the copper and directing themselves through the spirit to its surface are added to the particles of air scattered through the solvent, which also enter the bladder and inflate it; but this occurs only at the beginning of the solution. For if it continued longer, the bubbles rising from the metal not only would be less large, but would disappear entirely before reaching the surface of the solvent, since the solvent, eager for air (§25) would again disperse them throughout its pores; this we find not only for copper, but also for lead and mercury at the time of their solution; and so it is that no less amount of air, regenerated in the metal, is again dispersed through the pores of the solvent nor enters the bladder except at the beginning of the solution when it was added to it by the bubbles which were formed. Similarly, observe that not long after solution, when fixed alkali is mixed in, the spirit effervesces strongly, a clear sign that there remains in its pores after the process of solution a large force of the air. In order that it will not seem that we have suggested something arbitrary, we assume that 1312 parts (§25) of expanded air pass into the bladder from the pores of the solvent and the remaining 1000 parts actually are regenerated and expanded in the pores of the metal. Therefore the volume of the dissolved metal relates to the volume of air arising in its pores and expanding into the bladder as 1 to 1000; hence in breaking off any particle of copper there would act an amount of expanded air relating to the particle itself by a volume ratio of 1000 to 1; therefore the diameter of the bubble of expanded air after breaking off the corpuscle would relate to the diameter of the corpuscle as 10 to 1, that is, would equal 1/72 of a line.

§38

A cubic inch of mercury weighs 8 ounces 6 drams and 8 grains. Hence a cylinder of mercury supported by pressure of the atmosphere with a height of 28 Parisian inches, diameter 1/72 of a line weighs about 7 838 595 072 / 63 207 309 312 grains; since this weight equals the pressure of the air column which is above the bubble evolved from the pores of the metal (§37) and which supports this column, then the elasticity of the bubble equals the weight of this column of mercury. Since

this bubble before expansion, while acting in the pores of the metal on the corpuscle, was compressed in a space a thousand times narrower (§37) (here I do not consider the narrowness of the pores; for the air before occurrence of the elasticity does not occupy the volume of the whole metal, but the particular material of the latter occupies the greater part of the volume), then its elasticity will be greater by a thousand times, that is, will equal in weight 124 888 717 312 / 63 207 309 312 grains and hence will exceed the cohesion of the copper (§37) by more than 2 drams. Therefore it is not at all surprising that the particles of copper torn by such rapid motion from the surface of the metal are carried off through the solvent.

§39

After this, it remains for us to study the force which frees the particles of salt put into water from mutual cohesion, and distributes them through the water. In order to explain this we must first note that all salts contain a considerable amount of water which is abundantly separated from them in a receiver during distillation; and although from some volatile salts no water separates, yet by analogy and by the ease of their combination with water we assert the same thing concerning them.

§40

Salts dissolved in water on slow evaporation are converted into clear crystals, hence they take their form in water; therefore it is necessary to assume that the pores of the salts are filled with water. This is also shown by their transparency; for the body is porous and little transparent in itself, but being filled with water, it becomes transparent. Thus vitriol, heated on a slow fire to whiteness but in such a way that its most minute parts do not break down, is made opaque; but when it takes added water into its pores, it again becomes transparent. Sugar obtained by crystallization from water is transparent, but that formed by evaporation of the final form transmits light rays scarcely or not at all; however, water entering the pores makes it more transparent.

§41

Since the pores of salts (not heated) are filled with water, then salts, being put into water, cannot absorb it into them-

selves. Hence it is evident that the air scattered through water also does not enter the pores of the salts and therefore cannot expand in them from engendered elasticity nor act on the particles of salt.

§42

The correctness of this is confirmed by the following experiment. I placed a glass vessel half filled with water under the bell of an air pump and repeated strokes of the piston several times to remove the air; frequent air bubbles rose from the water. When I judged the water was sufficiently free from air, I exposed the vessel to the open air along with another vessel equal and similar in form to the first, in which was the same amount of water (from which, however, the air had not been removed). In both I placed the same pieces of rock salt of cubic form, weighing 50 grains; in the course of one hour the piece of salt which was dissolved in the water submitted to pumping out the air lost 27 grains, and in that containing air, 15 grains.

§43

It is evident from this experiment: 1) that air scattered in the pores of water not only cannot dissolve salts, but even is an impediment to this: how truly it hinders this will be shown in §47, and this itself will confirm our theory; 2) it is necessary to conclude that particles of salt are separated from each other by the action of the water particles themselves.

§44

When a solid body is made liquid, its particles are excited to a more rapid rotary motion. Hence, on liquifying salts in water the rotary motion of the salt particles is hastened. Since the salts are dissolved by the action of the particles of the water itself (§43), then it follows that the water particles, like a more liquid body, are rotated in faster rotary motion and approach the salt particles immersed in the water and touch them as well as the water particles which are homogeneous to themselves and which make up the mixed salts; these are set into faster rotary motion. Due to this the salt particles separate from the rest of the mass and, adhering to the water molecules,

begin progressive motion with them, and thus they are scattered through the solvent.

§45

When any body hastens the motion of another, then it gives to it part of its own motion, but to give part of its motion it cannot do otherwise than lose exactly the same part. Therefore the particles of water, in hastening the rotary motion of the salt particles, lose part of their rotary motion. Since the latter is the cause of heat, it is not at all surprising that the water is cooled in dissolving the salt.

§47[3]

Since air is scattered in the pores of the water, then the water particles, alternating with air particles, are somewhat rarefied, as the following experiment shows. We poured water which had been pumped free of air into a vessel with a narrow neck, leaving over it a small space filled with air. We closed the neck with a stopper and sealed it with wax so that no surrounding air could enter; during one or two days the air which remained over the water entered into it and the vessel appeared full of water; this clearly showed that the water was expanded by the air scattered through it. Therefore, when salt is put into water saturated with distributed air, a lesser number of particles of the solvent itself touch the surface of the salt and it acts on them more slowly so that their solution is slower.

§48

Of the actions mentioned up to now, by the aid of which solvents dissolve bodies placed in them, we can call the first *mediated,* the second, *direct.* For in the first case the solvent breaks off particles of the dissolving body by means of the engendered elasticity of the air, and in the second case the solvent itself acts by its own particles. Since mediated solution produces heat and direct solution cold, these effects should be considered as signs of one or the other.

3. [§ 46 is absent in the printed text.]

§49

Besides the solution of metals in acid spirits and of salts in water it remains to discuss amalgamation and partial solution; also extractions and decoctions, solution of bitumen in fatty oils, etc.; although these cases seem different from the first, yet we do not doubt that these solutions occur either by one or the other process, or both together. Since, however, there are few experiments which in any way serve for judging this and we have no opportunity to make new experiments, at present we will refrain from discussing them.

§50

In our problem, we started to explain why the specifically heavier particles of metals and salts were suspended in their solvents and did not sink according to the usual laws in specifically lighter liquids. But since all this is shown in sufficient detail by the most learned Freind[4] and Heinsius[5] we will refrain from repeating all this.

4. In lectures on chemistry.
5. In the description of the comet, 1744.

On the Luster of Metals

At a session of the Academy of Sciences on May 3, 1745, Lomonosov, then an adjunct, formally requested appointment as professor of chemistry, that is, as a full academician. He was requested to prepare an essay on some theme in the science of metals, and proceeded to do so in all haste. On June 14 he read his essay "De tincturis metallorum," and on August 7 he received the appointment he desired. This is one of the more clearly chemical writings of Lomonosov and offers the best evidence of his views on the nature of phlogiston. It was published in Latin in the *Commentarii Academiae scientiarum imperialis Petropolitanae,* 14:286-298 (1751). The Latin text and Russian translation appeared in *Collected Works,* I (1951), pp. 389-417, and the Russian translation is given in *Selected Works,* pp. 43-57.

§1

Those who have the pleasure of seeing a good mineral collection or who do not hesitate to crawl into dark and dusty mines well know how different and admirable are the bodies which nature bears in the bowels of the earth. Some minerals show a play of luxuriant colors, various and beautiful, and since they often appear themselves to be of the greatest value they lead those who do not know mineralogy into error. Other minerals, covered with a rough coating, deceive the gaze of inexperienced persons and seem worthless. Thus the outward appearance of precious metals is often ugly, and of the lesser metals, beautiful. Finally, many minerals have forms usually found in natives of the earth's surface, or of the air, or water: these are actually true animals or plants which after a very long time interval have acquired the hardness of rocks or actual minerals while still showing in their form their ancient, intricate nature.

§2

With the same admiration we see in the metals which we use when already refined and which are intrinsically hard bodies, the property of ductility and malleability, and we find

that these bodies, most worthy of the light of day and so lustrous, occur in the invisible depths of the mountains. By these very qualities they differ most sharply from other bodies, so that they can appropriately be defined as lustrous and ductile bodies.

§3

These unexpected qualities which make up the visible difference of metals from other bodies are inherent in certain of them to a greater degree than in others. Thus, some are converted easily enough by the action of fire into ashes and glass, losing their luster and ductility; others are not changed at all; to some we give the name precious, to others, nonprecious. The first include gold and silver, the other four are copper and tin, iron and lead.

§4

The qualities of bodies cannot undergo any sort of change unless there is some change in their insensible particles. But a change in a body can occur only if something is added or removed from it, or the arrangement of its particles is changed. The nonprecious metals when burned evolve vapors which affect the sense of smell and cause coughing. Lead is converted into a glass by a strong fire in the assaying oven and emits a smoke visible to the eyes; this effect clearly indicates that calcination and glass formation of nonprecious metals occur due to the removal of some of their particles.

§5

Although calcined metals increase in weight, whence we could conclude that this change is brought about by addition of some sort of foreign material, yet it is true that: 1) reduction of a metal mentioned below (§10 and 11) indicates the removal of material; 2) a metal which is converted to a glass loses in absolute weight; 3) increase of weight of calcined bodies can occur from an entirely different cause than from addition of any external material; this is agreed to by everyone who does not deny that gravitational material should act more strongly on the sides of corpuscles freed from mutual contacts by calcination.

§6

But if we remove by strong fire or by any other method particles of a mixed body which are similar to the whole body because of the qualities and composition of these particles, then the body does not undergo any change in qualities, but only its mass is decreased. This also occurs when we distill mercury or sublime sulfur. But nonprecious metals change their forms by calcination and glass formation (§3). Thus it is evident that they are mixed bodies and that at the time of calcination and glass formation some volatile constituent part is removed from them.

§7

As long as this volatile constituent part of the nonprecious metals occurs in them the luster of the metal and its ductility remain inviolable; and only when it is driven out by the violence of the fire do these metals break down to ash and finally melt into a brittle, nonlustrous mass. It is clear from all this that luster and ductility of the lower metals depends on this volatile principle.

§8

Although precious metals, undergoing the action of strong fire for months, do not lose their strength, yet analogy offers a very strong argument that a sufficient basis for their luster and ductility lies in some volatile constituent part which coheres to a fixed constituent part of them much more strongly. There are indications by famous chemists which show that gold and silver slowly and by prolonged calcination can be converted to ash.[1] This will be more evident from what is given below (§14, 15, 19).

§9

Since this volatile constituent part of the metals imparts metallic form to them and as it were gives them their lustrous color, then it is pertinent to give it the name luster.

1. Stahl in Treatise on Salts, chap. 31.

§10

Niter, though submitted to the action of the flame in a crucible up to red heat, does not burn with a flame unless we add to it a body containing inflammable material; then it immediately bursts into flame. Nonprecious metals in filings give a flash with this salt in the fire. Hence it is fully evident that there is some inflammable material in nonprecious metals. When this is driven out by an explosion, the remaining metal is converted to a glassy mass: therefore it is perfectly evident that the luster of nonprecious metals consists chiefly of this inflammable substance which is usually called phlogiston among chemists.

§11

The truth of this assertion is also supported by the reduction of metals which restores to glasses and metallic slags luster and ductility. However, for reduction of metals it is necessary to use phlogiston. The so-called black flux which is usually used for this purpose is nothing else than charcoal from tartar burned with niter. Litharge with powdered wood charcoal, calx of tin with charcoal from burned tallow, on ignition in the fire with sulfur and the herb Nicotiniana gain the form of metals. All these bodies are saturated with inflammable material.

§12

Another chemical operation shows this also. Thus, on solution of any nonprecious metal, especially iron, in acid spirit there emerges from the opening of the flask a combustible vapor which is nothing else than phlogiston, evolved by friction of the solvent with molecules of the metal,[2] and removed by the entrapped air with the more tenuous particles of the spirit. For: 1) pure vapors of acid spirit are noninflammable; 2) the calxes of metals destroyed by the loss of inflammable vapors cannot be reduced at all without addition of some body rich in inflammable material.

2. Our Dissertation on the Action of Chemical Solvents, §§ 14 and 31, *Nov. Comm.*, Vol. 1.

§13

When iron is dissolved in very concentrated oil of vitriol, a black powder falls to the bottom, which shows the presence of sulfur.[3] The latter consists of phlogiston and acid of sulfur whose properties are identical with the properties of vitriolic acid. Hence the phlogiston of the iron is added to the vitriolic acid which dissolves the iron, and thus sulfur is composed.

§14

According to Becher,[4] a black powder is formed from mud impregnated with linseed oil, rolled into balls, then roasted and freed from the lighter earth; from this iron is extracted with a magnet; in the iron is gold; this is never found without the linseed oil. For preparation of bronze from copper we take calamine and add to it ground up wood charcoal so that part of this mineral, taking on the nature of a metal, is reduced and can combine with copper.[5]

§15

The facts given previously are sufficient to establish the correctness of the position which we gave in §10. Though all this relates more to the nonprecious metals, yet their easy combination with the precious metals on fusing shows perfectly clearly the similarity of these in their luster, the more so in that the color of the most precious of all the metals is strengthened by the phlogiston of the nonprecious metals. Thus regulus antimonii martialis or venereus which are impregnated by the phlogiston of iron or copper give a more beautiful color to gold. When in the purification of metals we use stronger waters we try to retain in them the subtle vapors which are evolved with the solution (and also the inflammable vapor, §12) by adding the metal in very small portions to the solvent,[6] so that with the aid of this vapor the gold is extracted from the pure silver.

§16

That metals attain luster in the depths of the earth is shown

3. Stahl, Treatise on sulfur.
4. On Mineral Ores.
5. Stahl, Treatise on sulfur.
6. Kunkel, Chemical Laboratory, part III, chap. 26.

quite evidently not only by gold, silver, and copper, which are often found free, but this is also indicated for those metals which occur in combination with other minerals. Thus, spirit of niter dissolves several pyrites rich in iron; here the sulfur which is united with the metal falls to the bottom in the form of a powder,[7] an obvious indication that iron, even in a vein, does not lose its phlogiston, since a metal lacking its phlogiston should not undergo the action of spirit of niter at all. Note that with calcined metals sulfur does not give minerals, but with uncalcined ones it does.

§17

The foresight of the supreme Deity has so provided that mankind, scattered over the surface of the earth (and what part is not inhabited) would everywhere find metals for the satisfaction of its needs. Since for their formation a vast amount of luster-giving phlogiston is required, there is divine foresight in the appearance in the rich, deep bowels of the mountains of the fatty mineral which we call sulfur, due to which the metals were not only created at some time in the youngest period of the world, but are generated in large quantity up to the present day.[8]

7. Stahl, On Sulfur.

8. Many, however, will assert that all metals were created by God at the creation of the world where they are now discovered by the work of miners. Nevertheless, there is very weighty evidence which testifies to the contrary, and I wish to present some of this here. In the Swedish province of Angermannia the inhabitants work a vein of iron at the bottom of a lake; and when they have recovered from the bottom all the substance, so that no more remains, then after 20-30 years it is again renewed and yields a harvest (Swedenborg, Operum phil. et Met. Tom II, class I, § 4). In the Duchy of Tuscany near Mount Vesulan there is a lead mine where the shafts and underground passages 10 years after removal of the ore are again filled and are again worked (Bruckman, Magnalia dei, Tom I, cap. 10). The island of Ilva [Elba] in the Sea of Tuscany is very rich in iron; the worked out metal on it is again renewed after 10 years just as it was in ancient times, according to the report of Virgil (Aeneid, Lib. X, v. 174): "The Island of Ilva abounds in inexhaustible iron ore." In the mines of St. Lawrence in Abertamii, exhausted 20 years earlier, was found native silver generated on the wooden posts (Löhnheiss, Bericht von Bergwercken, I Theil). Of all this evidence, however, the most weighty is the impregnation often observed by miners in a fruitless vein by exhalation to form a rich vein, a process which the Germans call *Wettern*.

§18

Earth contains in its depths such a quantity of sulfur that it is not only accumulated underground (we do not know a single mine or a single type of metal which would not contain sulfur[9]), but this mineral is even separated on the surface of the earth. In the islands of the burning Indies and in cold Iceland the mountains bear so much sulfur that their covering would seem to be gilded. Mineral springs often have natural flowers of sulfur. This is indicated in addition to everything else by the fires of volcanoes, where sulfur cannot be consumed, though they burn with great flames in the course of many centuries.

§19

The following shows that it is just the phlogiston of sulfur which gives luster to metals in the earth. 1) Sulfur converted to a powder and ground with sand or mud and treated as described in §14 with mud and linseed oil gives metals.[10] 2) The same mineral colors metals a brighter color, which can be seen in the bright minerals of lead and in pyrites composed of sulfur with iron and copper. 3) Gold, slowly ground with saliva and water, gives a sulfur odor.[11] 4) But still more convincing is the complete identity of the phlogistons mentioned. Actually, just as metals are reduced from calxes and glasses for the most part by wood charcoal as we mentioned in §11 above, so also is the sulfur regenerated from oil of vitriol when in combination with a fixed alkali by the addition of powdered charcoal it first passes into the liver and then by addition of distilled vinegar milk of sulfur precipitates.

§20

Nevertheless, metals differ considerably from each other in luster and ductility: the reason for this difference can be sought in the remaining component particles of the metal which are mixed in various proportions with phlogiston and are held along with it to the surface of each corpuscle of the metallic mixed body. Then since the luster and ductility come

9. Löhnheiss, Bericht von Bergwercken, I Theil.
10. Stahl, Fund. chym., p. 102, § 14.
11. Stahl, Fund. chym., capite de auro.

from the phlogiston, it follows that the more lustrous and ductile the metals, the more thickly does the phlogiston occur on their surfaces as compared to those which are less lustrous and ductile; and where the inflammable material adheres less thickly to the surfaces of the corpuscles of the mixed body, there the particles of their other constituents must be interposed and must be seen through the intersticies.

§21

We are convinced on the basis of sufficiently weighty facts that an acid principle adds to the luster of some metals, and in each in a different amount. For metals obtain their phlogiston from sulfur (§20), but have a binding quality inherent in acid bodies. Further, all metals are dissolved by acid spirits, and the faster, the more binding they are. Since dissolving a body in a solvent greatly helps its homogeneity,[12] there is no doubt that in metals, especially binding ones, along with phlogiston there is also acid. Therefore Swedenborg[13] not without reason considers that the raw sulfur which enters the composition of iron is indeed the acid of sulfur combined with phlogiston. Compare the experiment described by the illustrious Pott[14] who in his words obtained cinnabar from metals dissolved in spirit of niter, precipitated by common salt or its spirit, and distilled with mercury. Related to this is the fact that silver fused with sulfur is converted into a soft mineral, *Glass-Ertz,* not unlike lead; thus on addition of sulfur, metals up to now precious, very ductile and lustrous, come to resemble the nonprecious in character.

§22

Arsenic has the property of giving metals luster; tin gives hardness and sound and makes them more dense; copper and iron whiten, and combined with nonprecious metals by alloying and long treatment improve their particles.[15] Therefore it is very likely that some arsenic particles take part in the luster of metals (especially metals which when dug out of veins are

12. Our Dissertation on the Action of Solvents, § 10, *Nov. Comm.*, Vol. 1.
13. Operum Phil. et Mental, Tom II de ferro, Class. I, § 1.
14. Dissertatio de sulphuribus metallorum, § 4.
15. Pott in Dissert. de anat. auripigmenti, § 13.

more often combined with arsenic than with sulfur), and that thanks to this they are distinguished from others by their luster and tensile strength. This can be asserted first of all with sufficient basis for tin. Actually, 1) this metal is always found in earth containing arsenic. 2) Its ductility yields much in tensile strength not only to the precious metals but also to some of the nonprecious metals (and the ductility is weakened by some principle while the heterogeneous fire material adds to the luster, §19). We have decided not to ascribe that which adds to the luster to the universal acid which with tin is less binding than with other more ductile metals. 3) Tin is more inclined to dissolve in spirits containing acid salts. As far as it is analogous to arsenic we can see that tin alloyed with silver in the substance hornstone and sublimed gives a poisonous material resembling arsenic in outward form.

§23

There is a strong suspicion that also in the phlogiston of silver and copper there are some arsenic-composing particles, since they are both often extracted from earth along with arsenic. When the vein of arsenical copper, built up into a pile, is dried by fire in the course of a month or more and is prepared for smelting, there grow up most beautiful copper fibers, displaying all the colors of the rainbow and fully deserving the name of the tree of Venus. This I have seen with the most illustrious Henckel several times with the red silver ore called *Rothgülden Ertz.* This famous author heated lumps of arsenical silver for a month in sand, regulating the strength of the fire in such a way that the arsenic could be sublimed, though very slowly. Then the silver after volatilization of the arsenic was drawn out in fine fibers. Both these experiments show at once the homogeneity of arsenic with silver and copper.

§24

The statement (in §20-23) can be considerably strengthened by the fact that sulfur and arsenic, added in large quantities to metals by fusion, almost completely destroy their ductility. Therefore we suspect that regulus of antimony, zinc, and bismuth are nothing more than metals containing an excess of

sulfur or arsenic, or both, more closely bound to them and therefore making them brittle.

§25

Since the acquiring of luster is not a little affected by even distribution of the particles on which the rays of the sun are reflected parallel, and shine more than on the disordered ones, it is not remarkable that in the semimetals mentioned above there is still some luster, though they do not have any ductility.

§26

In order to report all this more clearly and to show this more strictly, we could give still more and still could never give all that we intended several years ago; in the absence of a chemical laboratory,[16] we are prevented from carrying out these experiments and therefore we lack the conclusions to be drawn from their evidence.

§27

It is true that it is well known that there are some experiments which show how to remove sulfur and luster from metals; these experiments can be seen in the dissertation of the famous Pott on the sulfur of metals; but it is not easy to believe that these constituent parts of metals can be removed by themselves in pure and authentic form, since for their removal it is necessary to take salty and sulfurous bodies; although the latter are hidden under beautiful names by the expositors, we nevertheless cannot fail to suspect that in their use as media for extracting metals they are combined with the mixed corpuscles of the metals and very often, if not always, they give to them what is sought.

§27[17]

Most of all, to conclude, we consider it not unnecessary to add some conclusions based on the analogous assumption of

16. This was true when this dissertation was written in 1745. However, one was constructed in 1748 during the presidency of the Academy of the most illustrious Count Razumovskii.

17. [The number of this paragraph is repeated in the text.]

the transmutation of metals, coming, as we assume, from the transmutations of their luster which we have studied.

§28

Whoever looks into the spagyric art, even from the threshold, knows that weaker acids are driven off from alkalis by stronger ones and, as it were, separated out. Thus, vinegar is removed from potash by adding spirit of salt; this itself yields place to spirit of niter which is removed by stronger acids like sulfuric. Sulfuric acid is considered by chemists to be the purest of all and the most free from other types of particle; for they maintain that in spirit of niter there is something combustible and in spirit of salt some arsenical particles; that vinegar is contaminated by empyreumatic products is shown by its distillation through sand. Acid particles are more and more weakened in this process and are less able to combine strongly with alkalis. Their specific gravities agree with this, for the more concentrated the acid spirit of sulfur, the greater is its specific gravity, so that the heaviness of the spirits is increased by their acid particles. Thus a cubic inch of oil of vitriol, which is of the same nature as spirit of sulfur, weighs 7 drams 59 grains; of spirit of niter 6 drams 24 grains; of spirit of salt, 5 drams 49 grains; of distilled vinegar 5 drams 11 grains.[18]

§29

We consider that nature, in transmuting metals, can behave in a similar way to the working of masters of the chemical arts. More concentrated phlogiston, coloring the more precious metals, adheres to them more strongly. For we believe that if anyone, very skillful in the chemical art, has the most concentrated phlogiston most carefully purified from foreign substances, then he can precipitate and convert the lower metals into more precious metals.

18. Eisenschmidt in Disquisitione nova de ponderibus et mensuris, p. 174.

Dissertation on the Origin and Nature of Niter

In a letter dated January 31, 1748, Euler wrote to Schumacher, the secretary of the St. Petersburg Academy of Sciences, telling of a prize which the Berlin Academy of Sciences was offering for the year 1749 on the subject of the origin and composition of niter. He suggested that Lomonosov offer an essay on this subject. Lomonosov accepted the suggestion, though it was not until January 1749 that he actually began to write. His essay was completed in March and was received by the Berlin Academy on March 29, 1749. Lomonosov did not receive the prize, which was awarded to a certain Dr. Pietsch. His essay, written in Latin under the title "Dissertatio de generatione et natura nitri," remained in manuscript in the archives of the Berlin and St. Petersburg academies until it was discovered and translated into Russian by B. N. Menshutkin in 1934. It is the most purely chemical of all Lomonosov's general writings and shows very well how he interpreted the results of analysis and studies of chemical reactions. The Latin and Russian texts appear in *Collected Works,* II (1951), pp. 219-319, and the Russian translation is in *Selected Works,* pp. 81-121.

> As much as the acquaintance with principles means for chemistry, so much do the principles themselves mean for bodies.

INTRODUCTION

Among bodies which the chemist calls salts there are especially many uses for niter, particularly the surprising action, resembling the lightning, which it produces in gunpowder. Therefore it is not astonishing that the spagyrists, studying nature, have devoted much work to the study of the principle of niter. They were prompted to this by the tendency to become acquainted with such a wonder; but accompanying their work the most beautiful effects and useful products pushed

them on to further work. Their attempts did not remain unsuccessful; at the present time the composition and method of origin of this body have been disclosed and illuminated by many fine experiments and discoveries of the heroes of chemistry, famous in this and previous centuries; and it would seem there is nothing further to wish than that the results of their outstanding labors for explaining this be systematically developed in a more orderly manner by applying the geometric method. This is especially so if the elasticity of niter burned in a mixture with charcoal, which empirical chemical writers usually do not touch upon, is explained starting from the nature of niter itself and from physical experiments. Although these seem difficult, since up to now no basis has been laid in general physics for explaining the origin and components of such a body and there has been little success in applying physical experiments to chemistry, nevertheless we consider it possible through scientific relations to express the greatest part of chemistry in terms of special positions recently taken in physics; we do not doubt that we can easily uncover the hidden nature of bodies if we combine physical truths with chemical ones. When all the chemical truths are consolidated by stricter methods and it becomes clear how much one truth can be explained or brought out from another, then chemistry itself will be a science, and finally it may be seen more clearly what different branches of other natural science will offer for its explanation and how much it itself will contribute to its service. Then such a well worked out science will be carried on by the honorable members in the ranks of the physicists.

We wish to give an example of this in this proposed work and for this purpose, first, we will develop from the chemical point of view the composition and generation of niter, and then use physical effects connected with its nature to explain its elasticity. Hence there are three chapters: in the first we study the composition of niter; knowing this we already consider it not difficult to explain its generation, which makes up the subject of the second chapter. In the third chapter we will speak of the explosive force of niter.

The chemical assumptions on which we will develop these themes are the following:

Assumption I

Mixed bodies are composed of those constituents into which they are decomposed by analysis and from which they are formed by synthesis.

The truth of this is fully evident from the idea of the whole and its parts and does not require any demonstration. We remember only that in chemistry synthesis is often more reliable than analysis, and even it alone is sufficient to show the constituents. Analysis is not so dependable with respect to mixed bodies whose components are themselves mixed bodies: accordingly with different media used to separate the constituents there may be noted different components. Thus, on dry distillation of plants, we extract constituents which are far from those observed in their fermentation. However, in connection with synthesis, analysis gives much weight and is much used itself.

Assumption II

Between homogeneous principles and mixed bodies which contain in greatest amount the same principle, there exist some mutual interrelations by virtue of which they more willingly combine with each other than with heterogeneous bodies and, penetrating one another, they mutually combine. This combination differs from a simple cohesion, since by the latter only particles brought into contact are bound. Thus, watery bodies combine more avidly with watery ones, oily ones with oily, glassy ones with glassy, metallic ones with metals. On the other hand, heterogeneous bodies, though they cohere closely enough with each other (as can be seen from large enough drops of water adhering to a sloping board rubbed with oil), yet all their particles tend to mutual interpenetration with difficulty and can hardly combine. We consider it appropriate here to describe briefly how we present this, since we apply these hypothetical principles for a deep explanation of several questions. Everyone knows that particles of bodies cohere with each other on mutual contact. From the findings of Boyle it is evident that all particles have internal motion; we have shown in a separate dissertation, approved by famous men and soon to be published, that some of the particles have a progressive motion, all have rotational. Now [Fig. 1 was not contained in

the manuscript] let particle *C* adhere by contact to the surface *AB* of some body. Let it move about its axis by rotary motion from *a* to *b*; then, if between the surfaces at the point of contact *B* there is no friction, particle *C* will rotate at the point of contact *B* of surface *AB* and will not move forward to *B*. On the contrary, if at the point of contact of the plane there is friction, then under the influence of the internal force of motion impelling the particle to rotate and the cohesion which constantly maintains it, particle *C* will move on the surface *AB* in the direction of *B* and will penetrate into the first when the pores are large enough. For this reason also the particles of bodies mutually rubbing each other move relative to each other and shift their positions until a greater force of cohesion makes internal motion impossible. On the contrary, if there is no friction between the particles or there is only a very slight one, then such an effect entirely or almost entirely fails to occur. It is probable that the surfaces of homogeneous particles approach each other more than do heterogeneous ones and therefore their roughness from which, as we assume, friction arises combines them more with each other. Therefore, we assume, homogeneous particles are combined by the roughness, like gears, and in heterogeneous particles, due to the different sizes of the cogs, this does not occur (surfaces of homogeneous particles in contact are shown in Fig. 2 and of heterogeneous ones in Fig. 3 [p. 160]). Then there is no difficulty for any reason that homogeneous particles bound by linkages and having internal rotary motion would move around each other, and heterogeneous ones would not. According to this hypothesis we will call the mutual correspondence of homogeneous particles *congruence,* and we are persuaded by experiment that it can be used to explain chemical and other natural phenomena.

Just such action of particles can be the reason for the tendency of entrance of fluids into pores, the rise of bodies at the side of other bodies, as for example, the rise of mercury above its surface on the side wall of a silver cylinder and the spontaneous distribution of dry salt of tartar on the walls of a glass vessel up to its cover, and many other similar effects which can be ascribed to reasons of this sort. In order to study these more deeply and to show them more obviously, we would have to have a full treatise on chemical principles so that as a

result more closely related reciprocal facts would enlighten more fully. Since, however, the present theme neither requires this nor permits it, we will leave our stated hypothesis as a hypothesis, satisfied with the simplicity and probability.

Assumption III

If any body A, originally combined with body B, being separated from it, is shown to have the form and all the properties which it would have when mixed with body D, then body D is actually mixed with A and is received from body B: for example, when water in which gunpowder was soaked and diluted is passed through a filter, a liquid is obtained which is nothing else than a solution of niter, and so without hesitation we draw the conclusion: the niter now found in the water was before this mixed in the powder. This assumption can well enough be called incongruency.

All these three assumptions are not only sufficient for our purpose, but they can also easily be used for showing chemical truths which are confirmed below by examples. We add that we deliberately do not give definitions of substances and operations since we do not wish to trouble with statements of those things which are well known to everyone.

CHAPTER 1. ON THE CONSTITUENTS AND PRINCIPLES WHICH FORM NITER

§1

There is no doubt that *niter consists of fixed alkali salt and acid spirit.* Actually, chemical analysis produces both from it and shows them separately. On distillation, niter gives an abundant and very acid spirit, and if the distillation was carried out with oil of vitriol, the residue is nothing else than vitriolated tartar which is prepared from fixed alkali and oil of vitriol: clear evidence that the fixed alkali which along with oil of vitriol forms this neutral salt already exists in niter itself, since no one can assume its presence in the oil of vitriol (by assumption III). Then niter which explodes with charcoal, on losing its acid gives pure fixed alkali. The latter cannot be formed from the charcoal used in the operation since the

amount of charcoal taken for fixing the niter, reduced to ash and washed with water, gives only a few grains of alkali salt.

§2

Chemical synthesis itself reliably strengthens the correctness of this. Thus, the alkaline part of niter, previously separated by explosion from the acid, on mixing with spirit of niter again combines with it, and on crystallization gives the purest niter with all its properties; and if, instead of the fixed alkali of niter we take the alkaline salt prepared from wood ashes, especially the more solid, and combine it with the spirit of niter we also form true niter. Finally, the presence of alkali salt is so important for the formation of niter that in the absence of natural alkali its acid spirit will take to itself the fixed salt in associated minerals, and combined with the alkali of sea salt or even the alkali of urine forms a type of niter, different in form of crystal and in appearance, but not very different in strength of explosion and other properties of true niter.

§3

Thus, by virtue of assumption I, the conclusion drawn in §1 is fully true; therefore it is very strange that even famous people[1] have considered this assumption doubtful and have accepted that the alkali on distillation of niter is rather generated from the fire. Although after driving out the spirit from niter mixed with clay by fire they cannot find true alkali in the residue from distillation, yet they should not assume on this basis that there is no alkali in the composition of the niter. For we cannot deny everything that we do not see. This doubt evidently arises because the true course of the interaction between clay and niter on the fire was not known. According to the ideas of chemists which then prevailed, clay was mixed with niter to prevent its liquefaction which, as they thought, prevented the evolution of the spirit. But it is sufficiently known from glassmaking that fixed alkali salt used with earthy bodies gives a glass by removal of the volatile parts which were in the

1. Boerhaave, *Elementa chymiae,* Vol. 2, part 3, expt. 134; Lemery, *Cours de chemie.* p. 456.

mixed body; therefore evidently we can conclude that with this very strong fire which is used for driving off the spirit of niter from the clay, the alkali of the niter attacks the earthy material of the clay and, losing the volatile spirit, combines with it more strongly; thus also the spirit is separated from the alkali and therefore the alkali itself either scarcely can or cannot at all be washed out from the clay by water. Confirming all this is the differing ease of driving off the spirit of niter; from a mixture of niter and oil of vitriol it is driven out by a light fire, but from a mixture of niter with clay, by the strongest fire; that is, the alkali of niter is more avidly combined with oil of vitriol than with the earth of the clay.

§4

In order to learn in turn the nature of the constituent parts of niter, it is necessary to study the general properties of both the acid spirit and the fixed alkali salt. Thus we must find whether this alkali of niter differs from other forms of fixed alkali salt, and its acid spirit from other spirits of the same type. We begin with the acid spirit which is the more simple and thus more general than fixed alkali.

§5

The chief acid spirits which are usually produced by mineral and plant bodies are these: spirit of sulfur, spirit and oil of vitriol, spirits of alum, niter, common salt, vinegar. Each of these contains water even if we consider the most rectified spirit; they all, combining with the dryest alkali salts form on distillation tasteless phlegm. Then all in general are similar in corroding ability and acid taste, but differ in their strength and other properties. *It is certain that the corroding power and acidity are produced in individual types of spirit from one and the same principle.* Hence, with other conditions equal, each separately should have the same strength. Since, however, this is not a fact, then a sufficient cause lies beyond this principle; the latter blunts the strength of the acid when it is mixed in different amounts with the acid principle. Hence follows the conclusion: *the greater the blunting of the corroding strength and acidity, the greater is the amount of the other principle in the acid spirit; and on the contrary the stronger*

the corroding strength and acidity, the more of their own principle is present in the acid spirits. This truth is also widely confirmed by experiments. Thus, even the strongest acids, sweetened by spirit of wine, are usually very much weakened. Although water also weakens acids, yet differences between them cannot arise from different amounts of water, which is evidently confirmed by this fact, that acids, even diluted with water, retain their own qualities.

§6

Although the different strengths of acid spirits are also clearly seen in solution of metals, yet since there is no single acid spirit which can dissolve all metals, by reason of the different congruency of metals (by assumption II) with the foreign constituent part of the spirits, then we cannot draw on this basis a reliable conclusion about the degree of their acidity and corrosive strength. Therefore here we must use a more general criterion. With no other body do acid spirits combine more strongly and avidly than with fixed alkali salt. They tend to take it up, pushing out other metals and minerals which they had previously dissolved and kept in their network. This is done with different forces and tendencies, due to the different strengths of the acids, which act very differently in them, since the more powerful spirits acting on alkali salt drive from it other weaker spirits. Thus, vinegar yields place to spirit of sea salt, the latter is driven out by spirit of niter which in its turn is forced out by spirit of vitriol or, what is the same thing, of sulfur or alum (which do not reciprocally replace each other). Hence it is evident that *spirit of vitriol (and the related spirits of sulfur and alum) are the strongest of all; the remaining ones, those of niter, salt, and vinegar are weaker and successively the latter are combined with the other principle; the first consists of pure acid principle when present in the purest state, or in any case, contains less quantity of admixed side principles.*

§7

We find good confirmation of this in the different specific gravities of the spirits. That pure acid material, the chief constituent part of the acid spirits, has considerable density is evi-

dent from the following considerations. Sulfur certainly consists of vitriolic acid with a small amount of phlogiston combined with water. That phlogiston is specifically lighter than water is indicated by the floating on water of ethereal oils and rectified spirit of wine. Since sulfur itself is twice as heavy as water, it follows directly from the laws of hydrostatics that the specific gravity of vitriolic or sulfur acid should considerably exceed the specific gravity of water and that, hence, acid spirits are specifically heavier, the more acid principle they contain. Vitriolic acid and its relatives after most careful rectification and purification exceed the rest of the acids in their specific gravity, as shown by the hydrometer, and the greater difficulty of converting them to a vapor on distillation. Therefore there remains no doubt of this, which confirms §6 as entirely true. On this basis the most famous chemists take vitriolic acid for the universal acid and consider it the simplest of all. Comparing spirit of niter with it, we will try to define the specific differences. This is not the place to study another type of acid, since we speak only of niter.

§8

Moreover, as we assumed in §6 and 7, the greater strength of vitriolic acid as compared to spirit of niter is shown in its precipitation of metals and in the fixing of mercury: it is fully evident that spirit of niter has in its composition some lighter material or more volatile principle. What the nature of this is must be established from the properties of the acid. The chief distinction in its properties is that the neutral salts formed by this acid and some alkali, when ground with charcoal explode with a huge flame and immediately burn up. Since this is not done by any other acid combined with an alkali salt and charcoal, then evidently spirit of niter, besides the universal acid and water, must have still another principle which is most inclined to the generation of a flame; which also combines with acid and water, which resists flame, and which, overcoming it and carrying it away from itself, explodes with a flame; there is no doubt that this purest inflammable principle is called phlogiston by many. We have already noted above that the phlogiston principle is lighter not only than acid but even than water (§7). Therefore it is natural that it transmits to

the heavy universal acid a greater volatility and along with this it lessens its strength: hence the *spirit of niter consists of the universal acid (§5) and the phlogiston principle, combined together and intermingled with a watery liquid.*

§9

No little significance for confirming this truth is found in the congruency of spirit of niter with those bodies which in all probability have phlogiston in their composition. Thus, camphor rejects all other acid spirits, but combines with spirit of niter and goes over into a tarry substance. Ethereal oils combine very avidly with this spirit and give off a large amount of heat and even flame; though such action is found for some other acids, yet it is much less. For they act on these oils only by virtue of the acid spirit included in the latter, but spirit of niter attacks their phlogiston with its phlogiston, and their acid with its acid, which naturally should evoke a stronger motion and more considerable heat. Spirit of niter dissolves all metals and semimetals except gold, the more energetically and the more strongly, the greater the amount of phlogiston in them and the more manifestly the latter shows itself in them. After its expulsion by calcining the metal, the calxes undergo the action of spirit of niter very little, while vitriolic acid, on the contrary, acts much more willingly on the calxes than on the whole metals, which gleam from their phlogiston. Finally, oil of vitriol, mixed with rectified spirit of wine, combines without effervescence and although heat is evolved, yet it is less in degree than on mixing it with water.[2] On the other hand, fuming spirit of niter with water produces less heat than oil of vitriol, but with rectified spirit of wine produces a huge and appalling effervescence with heating to 180° and even more[3] and if to one dram of spirit of niter we add one dram of alcohol, a hotter effervescence occurs, after which nothing remains, but everything evaporates into air.[4]

2. The illustrious Pott in *Exercitatione de acido vitriolo vinoso* and the illustrious Muschenbroek in *Addit. ad exp. Acad. del Cim.*, par. 2.

3. Muschenbroek, *ibid.*

4. Hoffmann, *Observationum*, p. 40.

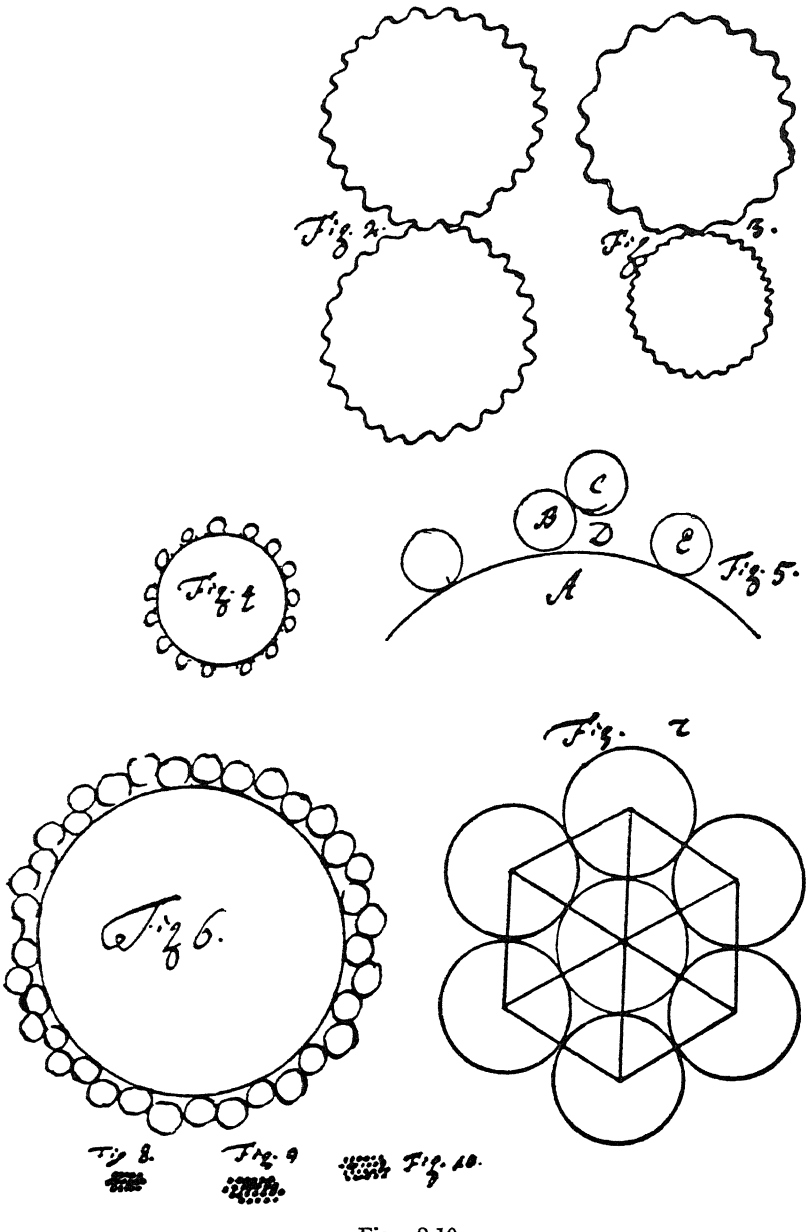
§10

Besides the acid principle, phlogiston, and the watery liquid with which the first two intermingle, we cannot admit that any other principle is in spirit of niter, and therefore we are limited to establishing these three component parts. There is also no necessity to discuss the specific properties of these liquids, since the theme under discussion requires consideration only of those properties which can explain the genesis of niter. Finally, it would be very interesting and useful to know in what ratio by weight or by volume are the component parts of this perfectly pure spirit; but from the experiments made up to now this cannot be determined exactly. It is evident only that the acid principle occurs in much greater amount than phlogiston, since: 1) the taste of the liquid is very acid; 2) it itself is not susceptible to flame; 3) it is heavier than water in specific gravity, and this would be lowered if phlogiston were more abundant; but even their approximate ratios cannot be shown. The relative amount of water was studied by the ingenious Homberg;[5] he added one ounce of spirit of niter to the driest alkali and from this mixture drove off the water into the air by a strong fire, leaving the acid principle; he found a loss in weight of 5 drams and 49 grains. Therefore water by weight is related to the other constituent parts of the spirit by about 8 to 3.

§11

Fixed alkali salt has earth in its composition. For: 1) after long digestion it yields an earth, tasteless, insoluble in water; 2) it is formed on combination from bodies rich in earthy substances, so that the more solid and firm are the parts of plants, the coarser is the ash remaining after combustion and the stronger and more fixed is the alkali salt obtained. On the contrary, volatile mixed substances lacking in earth principle give no ash and alkali. These facts, by virtue of assumption I, confirm the statement. It is true that very solid bone and other parts of animals, like rotted plants, do not form such alkali salts, but this is not in the least to the detriment of the truth expressed above, since for the constituents of these bodies, be-

5. *Mem. roy. Acad. Sci.*, 1669, p. 52.



Figs. 2-10

sides earth is required still another principle (see below, §13), which, if it is absent from the mixed body in combustion or encounters an obstacle to combination with the earth on burn-

ing, cannot form alkali with the earth and remains a mere earth, as appears in the ash of bones.

§12

In order to confirm these phenomena, we should first of all mention the congruence of fixed alkali salts with earthy bodies. For fixed alkali salt enters into such close bonds with them that there is formed a transparent and very stable body, not decomposed by any known strength of fire. This is daily found in glassmaking. This combination of the substance mentioned with sand is marked by rare phenomena. Thus, if such a mixture of sand with fixed alkali salt is heated in a pot on a great fire to melting, the liquid suddenly starts to boil, gives a foam, and moves just as occurs on combination of an acid with an alkali; from it comes a thick smoke and a heavy odor of acid.[6] We consider it very probable that this acid smoke is the part of the volatile principle which enters into the composition of the alkali salt which the earth loses in combining more closely with sand (cf. §3) and hence we come to the conclusion that *in fixed alkali salt there is an acid principle combined with an earthy one*; but since we could assume that acid volatilization takes place not from the alkali, but from the sand, we must have more reliable data and concurrence with the effects discussed, which will remove all doubts.

§13

To obtain the alkali salt by ashing, we select plants rich in acid material, the so-called essential salts; the more of these, the more alkali is washed from the ashes. Therefore the plants from which the essential salts are extracted give less alkali than if they are not extracted.[7] Further, if the plant does not burn cleanly, but smokes and is slowly consumed by a smoldering fire, then much acid volatilizes from the plant and the ash lacks a considerable amount of the alkali salt.[8] Then if the plant, containing volatile acid, is dried before burning, it gives less alkali salt than the undried.[9] Finally, tartar, the most acid

6. Stahl, *De salibus*, ch. 8.
7. Neumann, *De alcali fixo*.
8. *Ibid.*
9. *Ibid.*

of all the essential salts, after distillation leaves a very black residue; the ash obtained from burning this residue on an open fire gives a large amount of especially caustic fixed alkali salt so that a very considerable part of the tartar passes into it; if, indeed, we add the acidified water, the spirit and oil which were previously removed by distillation to the remaining alkaline mass and then again distill as before, then almost no acid at all distills out and little oil, and almost the whole mass of tartar is converted to alkali.[10] From all this it is perfectly evident, 1) that *for the formation of fixed alkali salt, acid is certainly required (by assumption I); 2) that essential salts of plants are more strongly bound with earth by strong fire (§11) and pass into the composition of alkalis.*

§14

That the acid principle occurs in the composition of animal material is shown by the souring of milk and the discussion of the illustrious Lemery,[11] but this principle hardly yields to isolation and it cannot be coagulated in the form of an actual salt, either because it occurs in small amount, or (which is more likely) because it is hidden in combination with other principles and thus cannot enter into contact with earths nor is strongly bound to them at the time of combustion. Decaying of plants is always preceded by fermentation, which disperses the greater part of the acid. Therefore parts of animals and decaying plants after combustion and washing out the ashes do not give fixed alkali, and for us this is a very important reason against the contrary argument. No little weight is given by the above mentioned proposition of violent effervescence and heating of the acid spirits with alkaline salts; we mentioned before how their hatred and struggle, and now, more correctly, how liking and avid tendency to mutual comprehension, beyond doubt show the congruency of the constituent parts (assumption II).

§15

Concerning the joining of these constituent parts in the body

10. Boerhaave, *Elementa chymiae,* vol. 2, part 1, expt. 55.
11. *Mem. Acad.* 1720, p. 266 ff.

of fixed alkali salt, we think no one has doubted. However, among very prominent scholars the question has still arisen of the presence of the third constituent part, the principle of phlogiston. Indeed the most famous authors, Stahl and Neumann, assert that it is present in fixed alkali salt; on the other hand, others deny this, especially the illustrious Bourdelin[12] from his own studies. The first opinion depends on experiments and conclusions directly from them; the second on deeper discussion, reinforced by experiments. Confirmatory opinion is substantiated by the fact that to obtain alkali, oily substances are needed and their formation does not occur without some fatty material.[13] Therefore, removing combustible substances from vegetable bodies by spirit of wine, we obtain less potash from their ashes than without the preliminary extraction;[14] to which is joined the no less weighty argument, according to assumption II, that the purest and driest alkali is attracted by the most rectified spirit of wine; if both these substances, or either of them, contains any water, their mixing is difficult.[15] Therefore on mixing them the temperature rises from 49 to 54 degrees (Fahrenheit thermometer); but the heat is scarcely perceived if instead of very dry alkali we take spirit of fused tartar.[16] Contrary to this, Bourdelin from the same facts by which the above authors confirmed their position, draws a contradictory conclusion on the basis of the following account.

§16

He asserts that fixed alkali of plants comes from burning their essential or natural salt, on which the more fixed part of their acid salt in combination with earth forms alkali; the remaining more volatile part is either driven off by the fire so that pure alkali salt remains, or remains unaffected by fire and then the neutral salt, the nitrous, is washed out from the ashes, as Stahl himself indicates. In the first case, he says, the more subtle acid along with the more abundant oil produces a greater flame; in the second, with an insufficiency of fatty

12. *Mem. roy. Acad. Sci.*, 1728.
13. Stahl, *Zymot.*, ch. 12; Neumann, *de Alcali.*
14. *Ibid.; ibid.*
15. Boerhaave, *Elem. Chym.*, vol. 1, part 2, "de alcali et menstr."
16. *Addit. ad exp. A. del Cim.*, part 2, p. 158.

substance, occurring either because of using a drier plant such as tamarisk or because the fatty principle had been extracted by spirit of wine, the acid is combined with the alkali formed in the combustion and gives a neutral salt. Since, therefore, by the absence of the fatty principle or after its extraction from the plant there is formed an alkali salt, but it is hidden in the form of a neutral salt due to combination with acid, therefore he concludes that the presence of the inflammable principle is not a necessary condition for the formation of alkali, and therefore he considers that the experiments of Stahl and Neumann in themselves cannot confirm their hypothesis. From the experiment of Lemery, who by adding oil drove off vitriolic acid, which remained in the colcothar after distillation, he showed that acid which binds the fatty substance was driven off by the fire and scattered in the air.

§17

On attentive consideration of these contradictory opinions, based on both sides on sufficiently weighty evidence, we find that both are partly true, partly do not correspond to actuality. Therefore we, aiming for the truth, will reconcile both of them; and first of all, along with Stahl and Neumann, we accept the fact that *alkali salts have in their composition the principle of phlogiston, but in different proportions to the other constituent parts.* Second, we assert with Bourdelin that *fixed alkali salt is formed from burning plants not in proportion to the fatty material which enters their composition, but that by its agency the alkali is liberated from the more volatile acids of plants and remains free.* In order to show what follows, it is necessary to describe the different nature of the alkaline salts of which the chief are salt of tartar and the alkali salt of plants.

§18

Tartar is formed from the juice of grapes, rich in spirit, after completion of their fermentation. Phlogiston is found remaining in the tartar after very strong fermentation; and since it is especially volatile in its nature, it is certain that it has escaped the force of such great motion by being strongly bound to the acid of tartar or with the earthy substance of tartar.

Hence it follows that this phlogiston can more strongly resist the action of fire and more easily combine with earthy and acid principles in fixed alkali salt than if no preliminary fermentation had occurred. The fact is different with plants simply burned. Their juice is much poorer in amount of spirit than that of grapes; under the influence of the flame it is scattered, setting in motion the more volatile phlogiston (so called wild), and there breaks forth with it even that which could resist fermentation and flame. Therefore it is clear that in the ash of plants much less phlogiston can remain than in the dry residue of tartar. Since tartar salt is coagulated with fats into soap, and most rectified spirit of wine is easily combined with this salt if it is perfectly dry, and there is even extracted from it a golden tincture such as is usually extracted in greater amount from fats, but this is not extracted from salts nor from bodies lacking phlogiston, then on the basis of assumptions II and III it follows that tartar salt includes in its composition the principle of phlogiston. On the other hand, although alkaline salts of plants also give soap with fats, and thus the presence of phlogiston is shown, yet they hardly combine or do not combine at all with the most rectified spirit of wine and do not give any colored fatty tincture. All this, in connection with what was said at the beginning of this paragraph, clearly shows that *the phlogiston principle is found in tartar and in alkaline salts of plants and more in the first than in the second.*

§19

Plants which before burning are dried, ground up, and treated with spirit of wine until they stop coloring it, then burned to ash, give little or no pure fixed alkali salt when leached, but do give neutral salt. Since this neutral salt consists of acid and alkali, we conclude that 1) extraction of resinous substance does not hinder formation of fixed alkali salt so that this fat contributes nothing to the formation of alkali; 2) since in this case, if the resin existing in the plant is not removed from it by any extraction, and after burning there remains pure alkali salt without acid, then it is evident that this acid adhering to the resinous substance is scattered from the heat. Therefore the conclusion of Bourdelin is correct. But it does not

follow from this that there is no phlogiston in the composition of the alkali salt, the more so that it is extracted by spirit of wine, but only the more volatile phlogiston leaves the more fixed, which after extraction arouses flame in the plant and can also enter into the composition of the remaining alkaline ash.

§20

Besides this the alkaline salts, especially of plants, differ in the quantity and quality of earthy substances: those which are leached from the more delicate parts of plants are more subtle and more delicate; and on the other hand, those leached from the thicker stems are stronger and coarser. The quantitative interrelations of these constituents of alkali salts (not more than three of them have been found) still cannot be determined; there are no experiments from which we could draw any conclusions unless that phlogiston, as very subtle, is least of all in the alkali and in acid is very abundant, as can be judged from the preparation of salt of tartar from the pure acid. All these principles are modified by watery moisture depending on its amount, as is very well known.

§21

This is all we consider it necessary to say in general about alkalis, but most of what was said, almost all, should refer to the alkali of niter. We will say a few words about the remainder which is specific for niter; thus, 1) since for the preparation of niter we use the ashes of plants, as shown below, then it is certain that *the potash of ashes constitutes in great part the alkaline salt of niter*; 2) since to the alkali from which niter is extracted we add unslaked lime in addition to the ashes, it is very probable that *some earth of an alkaline nature enters into its composition.* This is confirmed by the following: 1) niter dissolved in water and long digested evolves earth;[17] 2) niter regenerated from its spirit and fixed alkali of plants is softer and more caustic, since its alkali on boiling in a tin vessel attacks it, but if its alkali is passed through unslaked lime it becomes more inert and loses its corrosive ability.[18]

17. Boerhaave, *Elem. chym.*, vol. 1, part 2, "de terra."

18. Stahl, *de nitro*, ch. 2 and 3.

But we will speak of this below (§).[19] Here, however, we remember that it is unreal to infer the properties of the alkali of niter from the properties of fixed niter, since the alkali in this is contaminated by the acid spirit remaining in it, which obviously departs when oil of vitriol is added. There is also a difference with respect to inflammability induced by combustion of niter: with inflammable fluids it becomes less caustic than on detonation with dry bodies, and it becomes especially caustic with metals.[20] This does not contradict the above statement (§1) since besides this the alkaline nature of fixed niter is well enough known.

§22

We consider what has been said about the composition of niter to be sufficient to discuss its generation. From the preceding we have shown that *niter is a doubly mixed body, that is, first of all it consists of acid spirit and fixed alkali salt; the latter is composed of acid principle more firmly bound to an earth and of a small amount of phlogiston and a calcareous earth, and all of this is more or less diluted with water. The acid spirit is made up of the same acid principle and phlogiston occurring in water.* The illustrious Neumann gave a ratio of fully rectified spirit of niter to alkali and both to water: acid ¼, alkali ¼, water ½.[21] The same theory was confirmed for the acid by Kunckel.[22]

§23

Such is the internal nature of niter, not at all clear to the senses as a whole, but subject to disclosure by chemical means. This gives the number of constituents, their qualitative and often even quantitative ratios; but with its aid it is impossible to guess the place and order in which are arranged the corpuscles of the constituents and the particles of the mixed body. This latter would be very valuable and useful for deeper study of mixed bodies if only it were complete and reliable. However, since this cannot be discussed even by an expert, we will

19. [No number given in text.]
20. Neumann, *de alcali fixo.*
21. *Dissert. de alcali fixo.*
22. In *Laboratorio chymico,* part 2, ch. 6.

attempt to guess about this, as far as possible, on the basis of the qualities of the constituents themselves and on the basis of the external form of niter. Since here the discussion cannot operate on a sufficiently firm basis, we will carry it on more hypothetically.

§24

Corresponding to the very fixed and inactive properties of earths and the rapid penetrating nature of the acid principle, the latter should consist of much finer particles than the first. Since acid makes up the greatest part of the alkaline salt (§20), it is very probable that one particle of earth is surrounded by several particles of acid principle adhering closely to it, and some particles of phlogiston are interspersed between them, and water surrounds on all sides, as shown in Fig. 4. When the acid spirit is mixed with the alkali salt, its particle *C* [Fig. 5] first of all touches particles of *B* which adhere to the earthy molecule *A* of the alkali and turn toward it around *B* (by the hypothesis of the introduction, assumption II); it then enters the small space *D* between *B* and *E* and displaces the air stored there. This air, driven out from several pores, collects in bubbles and expands in a foam, and the particles of this are heated by collision and friction. The particles of acid *C*, if it is pure and does not contain another principle, join more with the acid particles *B* and penetrate the space *D* more strongly and deeply. On the other hand, if it is combined with phlogiston or other principle bound to it, then it cannot so easily enter and settle so firmly there. Therefore spirit of niter, due to the interference of the phlogiston, adheres less strongly to its alkali and thus must be driven off by purer universal acid. Further, since the particles of the acid spirit, homogeneous among themselves, occur among the particles of alkali salt, forming along with the latter corpuscles of neutral salt [Fig. 6], then the acidity is lessened in the spirit and the acidity is modified; in the alkali salt the roughness is smoothed over, the causticity is lowered, and there is formed a neutral salt of a more delicate nature, so that the very penetrating spirit of niter and the alkali are combined in a body with not so sharp a taste.

§25

If we assume that a thus composed particle of niter has a

spherical form and that in great part the smallest parts of the body tend to collect into a cluster, we can very easily explain why niter grows in a hexahedral crystal. Although all this is based on one hypothesis, yet it answers exceedingly well the nature of the constituent parts of niter and therefore gains some weight. Actually, let six corpuscles be arranged around each other in such a way that the straight lines joining their centers form an equilateral triangle [Fig. 7]; as a result we obtain a figure bounded by six lines like the cross section of a prism of niter. The particles of niter thus arranged in almost infinite number form the crystalline prism of niter, true, often with unequal sides which, however, are always parallel and correspond to the assumed arrangement as shown in Figs. 8, 9, and 10. However, the guess which we have assumed is confirmed in three ways: 1) this process explains the form of the particles, which is not suggested by anything which the crystals of niter have in themselves, and the question does not then remain unanswered, as is often the case; 2) the angles of the niter crystals correspond to the assumed arrangement of particles, since usually each of them is 120°; 3) on the basis of our hypothesis we can easily explain other sorts of crystals, for example, the cubic crystals of common salt can be explained by assuming such an arrangement of salt particles that the lines passing through their centers make a square.

CHAPTER 2. ON THE GENESIS OF NITER AND ITS PRODUCTION

§26

In describing the production of niter we have arranged all the material as far as possible in such a way that we first discuss in detail methods of producing niter in Europe; then we explain the composition of niter itself and the character of the substances serving for its preparation and how they contribute to the formation of its constituent parts. Finally, we support our explanation by suggesting processes for rapid production of niter.

§27

As experiment has taught, the dung of animals, especially

horse manure which has lain long in a shady place, is whitened as if covered by frost, and equally so are walls made of clay and straw and covered with lime, which also whiten as if from hoar frost (the whitening occurs more rapidly by drenching with the urine of animals); as a result of known procedures this shows the presence of niter. Therefore the producers of niter carefully collect these materials for their needs and when they have noted that fresh bodies of this sort do not contain niter,[23] they begin to use those which have been aided by putrefaction. They collect not only the easily rotting parts of animal and kitchen wastes, but also plants which are undergoing rotting. From the walls of wooden huts constructed of clay and straw they take off a layer of a finger's breadth, which is granted to certain persons as a privilege of the state.[24] Then they collect the discarded soap boiler's ashes and earth from a cemetery. Moreover they avoid those substances which have lain long in the open sun. Also, from plant materials they mix fresh and fallen leaves from willow, fresh and delicate shoots of spruce and leaves of other fragrant woods, squash leaves, herbs containing stinging acid sap, straw of beans and peas, and finally, any plant thrown out of gardens and from fields as useless, for the construction of the very valuable niter piles. Sometimes they add sediment and wastes from brewery production, and also those obtained from distilling spirit of wine from grain.

§28

These parts of animals and plants are mixed with muddy earth and set out in the open air in long piles like embankments, parallel with each other, so that one pile protects another from the rays of the burning summer sun; therefore they are usually laid out in a line from east to west. Also they are enclosed with walls extended to a height of two sazhens and made of the same niter material; thus a shadow for the piles is attained, and in order that it be still larger, at the southern edge and also between the embankments are placed shading trees, which by the falling of their leaves also contribute to the piles. Further, since too abundant rain water would harm the

23. *Hist. Ac. Roy. Sci.*, 1717, p. 30.

24. Stahl, *De nitro*, ch. 2.

delicate niter which is forming, canals are placed around the piles; sometimes the piles are even covered with a straw roof, leaving free access of air at the sides. The piles thus prepared, kept from the action of bad weather, are repeatedly wet with decomposing urine or rotting pieces of kitchen waste.

§29

When the piles are enriched with niter, which is recognized by the whitening of the material adhering to their sides like wool or frost, the nitrous earth is taken and slowly dried in a shady place if there is moisture in it; then it is prepared for extraction thus. In a vessel with a double bottom in which the upper movable bottom, containing numerous openings, is separated from the lower by two or three fingers' breadth and covered with four inches of straw, is placed a layer of niter-bearing earth four fingers thick, and above this the same thickness of a layer of ashes obtained by burning hardwood powder mixed with unslaked lime. Then a layer of niter-bearing earth of the same thickness is put in, above it a layer of the same ash with unslaked lime, and so further, layer is piled upon layer until the vessel is almost entirely full. The number of such vessels corresponds to the quantity of nitrous earth. On top of everything hot water is poured, so that it covers all the material by two or three fingers' breadth. The whole is allowed to stand quietly overnight and on the next morning the opening in the lower bottom is unstoppered and the alkali is drained into another vessel underneath. The liquid at first runs cloudy; it is again poured over the niter-bearing material until it passes through more clearly. When the upper vessel is free from water, pure water is again poured into it and there is obtained through the draining outlet an alkali much weaker than the preceding. Both alkali solutions are then poured into another vessel with niter material and the drainage from the outlets of the vessel until the solution is sufficiently saturated with niter.

§30

Ash and quicklime are added with the niter-bearing material because the latter alone on washing out its alkali does not give true fixed niter; saturated with alkali it can scarcely be evaporated enough to give crystals, which moreover are very deli-

cate and fragile; on evaporating most of the water, they are volatilized and scattered into the air. These fine crystals obtained thus are much weaker in explosive force than true fixed niter; they much resemble the ammonium salt which is prepared from volatile salt of urine and spirit of niter. On the other hand, alkali passed through ashes and lime is enriched by the most fixed alkali, very strong and having great elasticity.[25]

§31

When the nitrous alkali is judged by examination to be ready for evaporation, it is poured into a copper pot, higher than it is wide and narrowing toward the bottom as a truncated cone. In it is placed a wooden bucket, filled with rocks, of approximately the same shape as the pot, but of much less size, so that between its walls and the pot there is space enough; its bottom is separated from the bottom of the pot by two or three fingers' breadth and its lip should lie at a considerable depth below the surface of the alkali. At one side of the pot, over the edge, is placed a tub filled with alkali and with an opening directed into the pot and open in such a way that as much alkali flows into the pot as goes out in the form of vapor on heating. During heating the earthy material is separated from the alkali and is collected in the bucket; without this it would be precipitated on the bottom and walls of the pot and would cause expense in money and work, as is evident from the book of Ercker[26] on the preparation of niter, when he still did not know how to use the bucket. This phenomenon results from different heating of the alkali found at different distances from the fire. Thus, in the space *AAA* (Fig. 11) between the walls of the pot and the bucket the alkali is heated more than in the bucket itself and therefore stronger motion takes place. Therefore the earthy substance mentioned, separating from the alkali and gradually making it cloudy, rises in the bucket to *EE,* goes toward *D,* and rapidly is precipitated in *C* because of the greater quietness of the liquid; the remaining alkali in part *A* is in strong motion so that it cannot settle before it has

25. Stahl, *De nitro,* ch. 1.

26. *Aula subterranea,* Bk. 5.

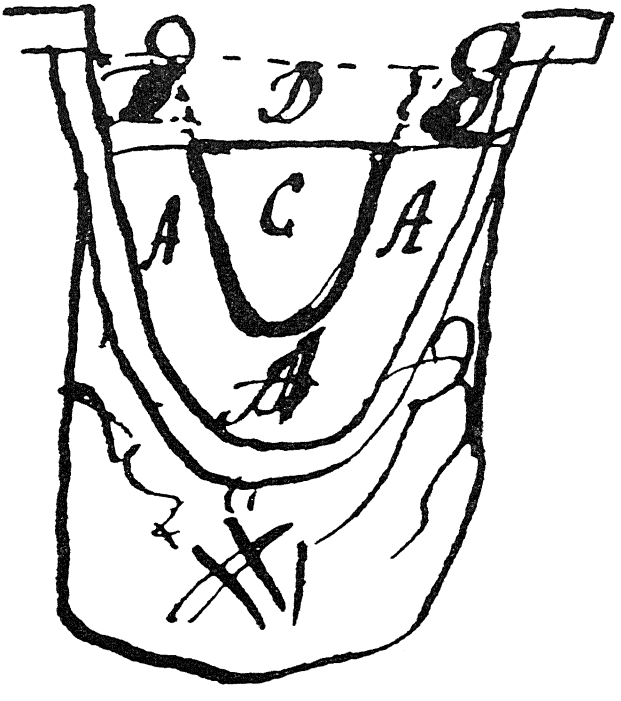


Fig. 11

collected in more considerable amount. After this time, the alkali, stirred up by the great heat, enters the bucket and mixes with the clear alkali and is quieted and precipitated; thus by continuous motion the earthy substance almost entirely precipitates in the bucket.

§32

The alkali, concentrated to a sufficient degree of saturation, is poured from the pot into tubs and stands in a cold place for crystallization. When the liquid is cooled, solid, transparent hexagonal crystals grow in it. The residual alkali on further concentration gives in great amount finer, more brittle crystals with less explosive power and often contaminated with common salt. After the end of the evaporation and crystallization, there remains a yellow liquid which does not produce a crystalline species; in German it is called *Mutterlauge,* mother of alkali, and the latter alkali is precipitated either by oil of tartar per deliquum, or also by vitriolic acid; it yields a white earth

called magnesia by physicians.[27] The same alkali converted into a solid body by evaporation evolves a brown, choking vapor; after ignition on a stronger fire, there remains in the retort a residue of the so-called magnesia.[28]

§33

At the end of the extraction, the earth, deprived of niter, is mixed with fresh earth with addition of suitable plant material and also manure and decayed parts of animals, which are sprinkled with the remaining mother liquor; everything is put into a pile and submitted as described above to the action of air, so that new niter will be formed. In the Paris Arsenal the niter piles are made of a mixture of earth already washed out and with fresh niter earth, layer on layer, and each layer is wet with the scum from the alkali of the first evaporation; and so that the earth may be reduced directly to niter, it is mixed with pigeon and horse manure and finally is wet with urine.[29] This discussion of the preparation of niter is sufficient for our purpose, and we now turn to an explanation of its genesis.

§34

Niter-bearing earth prepared for extraction of the niter contains in itself volatile niter, otherwise called ammoniated niter salt, composed of true spirit of niter and volatile animal alkali. The truth of this is perfectly evident from §30, since such volatile niter gives crystals with great difficulty, and very delicate and fluffy ones, and on evaporation is lost in great part, on heating is scattered in the air; with charcoal it gives a less strong explosion than fixed niter. To this we add that distilling pure alkaline nitrous earth permits preparation of aqua regia[30] which is usually obtained from acid spirit of niter and alkaline salt of urine.

§35

The volatile alkali needed for formation of volatile niter in niter-bearing earth comes from the rotting animal parts or

27. Stahl, *De salibus*, ch. 15; and Hofman, *Observati.*, p. 110.
28. *Ibid.; ibid.*
29. *Mémoires*, 1717, p. 44.
30. *Mémoires*, 1717, p. 49.

excrement; there is nothing to be surprised at in this. For who would seek in the distance for what is given by things nearby? And who would think of reaching that which is absent by rejecting that which is present? The more so that without rotting of animal excrement or parts there is no generation of niter in piles built up for this purpose, and for producing and hastening their rotting and for separation of the volatile salt we purposely add ashes whose fixed alkali does this and more rapidly frees the volatile salt.

§36

Plants have in their composition acid of niter. All plants, especially becabunga, wall pelletory, soap plant, artemesia, common wormwood, herbs purified and softened by preliminary extraction with spirit of wine of their resins by boiling or slow carbonization, show the presence of true niter[31] and hence produce the acid spirit from which niter is formed with alkali. This spirit often shows itself by other clear signs. What, pray, is this other fatal fume of charcoal, very similar in its terrible odor to aqua fortis; is it not an acid, very similar to that of niter, driven out by the strong fire?

§37

Spirit of niter is driven out from plants by fermentation and is volatilized into air if it is not caught. It is well known to all that plants in fermentation are changed and even destroyed. Here the changes found are that 1) an acid and an inflammable spiritous substance are evolved; 2) a precipitate is obtained which consists of a coarser earthy material and a remaining small amount of acid and inflammable spirit; 3) two sorts of acid are obtained: one which in fermentation volatilizes in great part into the air and another which at the end of fermentation remains and on later digestion passes into vinegar. The first, much stronger, on inhalation through the nose affects the nerves, dissolves some metals, and passes out into the air and rarefies; but the second does not act even on metals plunged into it. The presence of acid of niter which was in the fermenting plants cannot be assumed in the wastes, and

31. Stahl, *Elem. chym.*, p. 62. § 8.

therefore it must be sought in one of the acids mentioned. That acid which is diffused on motion transmitted to the substance by fermentation, on the basis of the preceding, comes nearer in nature to acid of niter than to vinegar. It acts in the same way on the sense of smell as spirit of niter and sweetens spirit of wine; this is not found in vinegar. Since, however, spirit of wine is also evolved with this acid spirit, it is evident that the spirit of niter formed in plants leaves them in fermentation combined with the spirit of wine and, if there is no medium ready which is capable of binding it, it volatilizes into the air along with the spirit of wine.

§38

Plants used for the formation of niter-bearing piles (§27) mixed with animal substances are destroyed. But this cannot take place unless they are first fermented, which, being a slow and often unnoted process, yet cannot be ended until everything has happened which was remarked in the previous paragraph. When the plant material is disintegrated by fermentation, spirit of niter combined with spirit of wine tends to volatilize into the air. But since it almost always meets the alkali salt volatilizing along with it, formed from the rotting animal substance (§35), then it remains, caught by it. At the same time the phlogiston of wine, previously in combination with it, is avidly combined (according to assumption II) with the animal fat not yet submitted to the action of alkali, and thus pure nitrous acid leaving it is more closely bound with the pure alkali liberated from the fat. And once this has occurred, it is necessary—we assume this is perfectly obvious—that *the nitrous acid generated from the plants, added to the niter-bearing mass and separated from them by rotting is combined in the niter-bearing piles with urinous alkali into volatile niter.*

§39

Against this, as I hear, scholars object, using great authorities and having great merit,[32] and assert that spirit of niter is formed from the air. We know that their opinion is known

32. Stahl, *Fund. chym., De nitro,* § 25, and Henkel, *Pyritologia.*

to everyone who has studied chemistry, and is even accepted by many; therefore we consider it inadmissible to pass it by, the more so that it is not entirely untrue. That an aerial element, and this truly nitrous, could be the bearer of an acid spirit is evident from this, that 1) volcanoes, taking up sulfurous material, throw out large amounts of acid spirits, as underground caverns also emit them; 2) no little are they emitted by fragrant plants which have an acid sap in growing and fermenting. It is evident that from the first source comes vitriolic acid and from the second, spirit of niter. Therefore it is not surprising that often alkaline and earthy absorbent bodies, long exposed to the air, especially if they are saturated by vapors from nearby plants, take up spirit of niter so that the ashes exposed to the air in the spring season in a shady place for several weeks show the presence of some amount of niter[33] and, with spirit of salt driven off from old tiles, dissolve gold.[34]

§40

But how far it is from the truth that a single aerial acid saturates the piles built for isolation of niter is evident even from the fact 1) that for constructing them a single alkali is not used; 2) that pure alkalis would more easily take the spirit of niter from the air than alkalis mixed with foreign bodies contradicts daily observation; 3) that Lemery, exposing to the open air in a place protected from the sun quicklime, salt of tartar, and carefully washed out niter-bearing earth for two years and even more, did not obtain even a trace of niter.[35] Further, acid of niter from plants treated in a niter-bearing mass was found near volatile alkali generated in the same mass by rotting animal substances. Therefore there can be no reason why it would be taken from acid scattered in the atmosphere. But, you may ask, why is the niter-bearing material exposed in the open air? I answer, in order that the rotting of the animal substances and the fermentation of the plants will occur more easily. Without free access of air both processes are hindered.

33. Stahl, *Tractate de salibus.*

34. The same, in *Fund. chym.*

35. *Mémoires de l'Acad,* 1717, pp. 39 and 43.

§41

When fixed alkali is added to the ammonia salt, the acid spirit, leaving the volatile salt, combines with the fixed alkali, which is evident from the driving off of ammoniacal spirit. No chemist doubts that the same thing occurs with all neutral volatile salts, including also volatile niter. Hence it is clear that the alkali washed from niter-bearing earth is passed through ash just for this, so that the alkali of the latter on expulsion of the volatile alkali will take to itself the spirit of niter and be converted with it on extraction and crystallization into fixed, true niter. By this synthesis we have again confirmed that fixed alkali salt is certainly required for the formation of niter (§3). It is true that the amount of ash taken for filtering the alkali can be shown not to correspond to the amount of niter obtained; it would probably require much more alkali salt for formation of niter than the water taken from the ash could give, but we cease to be astonished if we remember that the lye from the niter-bearing mass can extract more alkali from the ash than can water.

§42

Ordinary salt is separated from the niter-bearing alkali by repeated extraction (§32) though, as is known, it is not extracted from the pure niter-bearing mass. Hence, it is formed along with the fixed niter, and this spirit of salt, generated in the nitrous mass in the pile (which usually occurs on addition of fresh manure), combines with the fixed alkaline material in the same place and at the same time as the spirit of niter. Since the acid salt, acting on the alkali salt of the ash simultaneously with the nitrous, can harm the formation of fixed niter, another suitable alkali is needed so that the acid of salt bound to it will not prevent generation of the niter. The nature most like it is the alkaline lime substance with which it preferably forms ordinary salt.[36] Therefore we take quicklime for the preparation of nitrous alkali (§)[37] which has in itself the spirit of salt, separated from spirit of niter, and this congeals into ordinary salt and moreover, the more subtle parts of this substance permit blunting of the caustic niter (§29).

36. The illustrious Pott, in his *Dissert. de sali comm.*

37. [Number omitted in text.]

§43

Having established all this, I do not find it difficult to explain that which is found in the mother liquor. Since magnesia is usually precipitated both by acids and by alkalis, it is clear that this is a substance of neutral nature and consists of acid and alkali. Its alkali is weaker than fixed alkali, since it is precipitated by it. At the same time its acid is weaker than vitriolic acid, which follows from the same reason. It is certain that the volatile alkali which is driven out from the compound with acid of niter by the alkaline salt of ash is dissipated by fire on boiling. Hence it follows that the calcareous alkaline substance, dissolved in acid, forms the alkali mentioned, and after adding stronger alkali salt, precipitates the white powder of lime. But the acid in this compound is weaker than vitriolic acid and therefore should be acid of niter or of salt. Since the latter is contained less in the whole mass of niter-containing substance and the mother liquor gives off a brown, choking vapor (§32), which is certainly nitrous, on evaporation and calcination, then it is fully evident that this alkali consists of the more delicate alkaline substance of quicklime dissolved in more dilute acid of niter. Thus niter manufacturers act quite reasonably when the alkali is passed through fresh ashes so that combined with fixed alkali salt it is changed to niter.

§44

We consider that our explanation can be supported best by that process of preparing niter which is carried out with the greatest advantage in respect to work and time and which refutes what is sometimes stated but can be discarded according to our theory; the statement that the simultaneous fermentation of plants and rotting of animal parts is required for the production of volatile niter. If this can take place by a process requiring less time, then extraction and crystallization make up the minimum which is required for the production of fixed niter. This was long ago noted by Ercker who recommended for the most rapid preparation of volatile alkali brine, a body tending to decomposition and very suitable for obtaining uriniferous salt.[38] We have considered several processes but, burdened by many duties, we could test only one. This is: different

38. *Aula subterranea,* p. 189.

herbs thrown out of the garden and willow leaves in a clay vessel are macerated for several days at the temperature of a healthy man; to hasten the fermentation we add bread turning sour from fermentation. At the same time in another vessel is carried out putrefaction of kitchen wastes, decayed fish, and some quantity of putrefied urine is added; as soon as signs of beginning fermentation and putrefaction are seen in both vessels part of the fermenting material is removed and put into the second vessel with the putrefying substances; after an hour in its turn the substance from this vessel is transferred to the first. By repeating the transfer, movement is excited in both vessels; the mutual transfer increases the amount of substance and hastens the time, and the motion increases. Finally, when everything is placed in one vessel, carefully covered, after a day and a night motion ceases and above the precipitate is found a perfectly clear liquid. Passed as usual through ash, this gives a large enough amount of uncontaminated niter.

§45

We think it would be worth an inquiring study if whoever has the time would use a suitable form of volatile alkali for catching the fermenting spirit. We would not consider it fruitless also to add work on collecting the vapors of charcoal by fixed alkali. We will not say much about this, leaving it to the zeal of others. In general our theory permits easy explanation and understanding of the spontaneous generation of niter, almost always the volatile, which is an efflorescence on the walls of buildings and the limestone cliffs of India and Africa, especially where the necessary conditions are present. Many have overlooked, still more have falsely reported only from their imagination, concerning the niter of cellars cut into cliffs which is usually nothing more than earth scarcely penetrated by mineral acids; miners call this earth kieselguhr or sinter.

§46

It is clear from what has been reported in this chapter that niter is of plant origin. Though it is true that the principles of all the kingdoms of nature are the same, we also affirm that the component parts of niter arise from the components of plants except for that slight portion which is added to the

alkali salt from the quicklime. This truth is especially confirmed by the fact that a considerable quantity of niter can be obtained directly from plants (§36). It is a fixed and everywhere similar fact that nature never takes a round-about path when she can proceed by a direct route.

CHAPTER 3. ON THE EXPANSIVE FORCE OF NITER

§47

In the explosion of niter it is necessary to separate two circumstances: first that it explodes with charcoal; second that its flame surprisingly so greatly exceeds the fastest and strongest expansion of other types of flames by which other bodies explode. The first is not hard to explain by the combustible principle of acid of niter; the explanation of the second requires more labor and caution, the more so that it cannot be revealed from the previously explained nature of niter. It is therefore important to review other natural effects and to seek whether we do not meet some other similarities to the action of niter such as can be correctly applied to an explanation of this action. No other effect corresponds more to the great power of niter to give an explosion than the effect of air escaping after strong compression when its barriers are weakened or destroyed. Therefore an air gun made ready for firing is less in strength to this, it is true, yet it is entirely similar in action. Comparing these effects and taking into consideration the cleverness of nature which is so generous in various actions and so sparing in its principles, it easily comes to mind that the explosive force of niter depends on the air freed from its pores due to destruction of the niter itself. We assume that this was suspected even by Stahl[39] who asserted that in niter there was a vaporous air and at the time other bodies were extinguished in the absence of its access, niter had sufficient air within itself. In order to study properly this preliminary assumption, we must study more attentively the air included in the pores of the body.

39. *De nitro*, ch. 1 and 3.

§48

It is well enough known from the experiments of the illustrious Boyle that a body on destruction gives off an elastic fluid, very similar to air, which this most learned man called factitious air.[40] After this Boerhaave did not hesitate to call this fluid unreservedly air and he considered that he found it in bodies in such an amount that in water it was more than the water itself.[41] There were not, however, experiments which could confirm this truth so that no doubt remained, and then the famous Hales[42] by incessant work not only did this but also determined for many bodies the amount of air included in the narrow pores. The experiment showing that true air

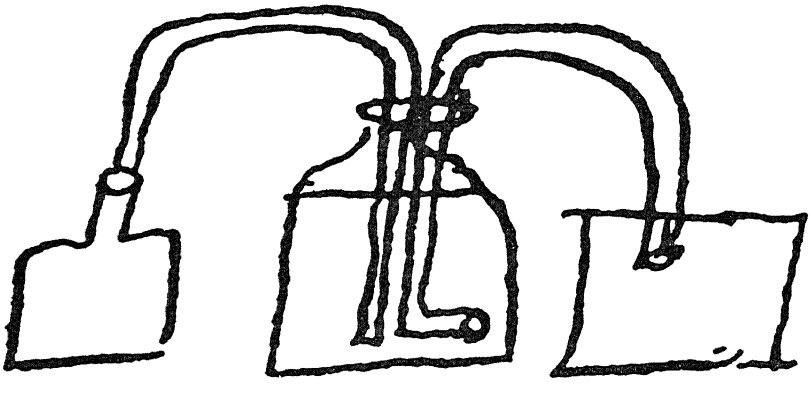


Fig. 12

is found in very large amounts in the pores of bodies is this. The factitious air obtained from human calculi was kept by this author for three years, but he could not see any change in it. He found that its specific gravity was the same as that of ordinary air, that in both the elasticity was the same, and moreover, the factitious air compressed for several days lost no elasticity.[43] Although we had assumed otherwise, we found a sufficient similarity in the effects. Namely, on mixing alkali with vitrolic acid, spirit of niter, and other acids, and also on dis-

40. In *Experimentes novis physico-mechanicis.*
41. *Elementa chym.*, vol. 1, part 2, De aëre.
42. *Statica vegetabilium.*
43. Hales, *Stat. veget.*

solving metals, we obtained a great amount of this elastic fluid, often a hundred times surpassing the substances taken, and we found that in all its properties it was entirely similar to air. In order to separate from this elastic fluid the vapors to which some ascribe its expansion, we passed it through spirit of wine and through an alkaline solution. The elastic fluid thus obtained, more pure, remained very similar to air when kept for months [Fig. 12]. It was compressed by cold, expanded by heat, underwent compression, and on removal of the compressive force recovered the original volume, ascended through water and other liquid bodies in the usual form of bubbles, and, as our findings showed, never disappeared except in cases when the liquid body was deprived of air by the air pump.

§49

From all this it fully follows that fluids obtained from dissolved bodies are natural air, since these findings have the same force as chemical analysis; but for better evidence we can use the analogous argument of synthesis. Thus, in several experiments Hales noted that amounts of air were absorbed by some bodies many times greater than themselves. Thus, one dram of volatile ammonium salt absorbed 2½ cubic inches, whence calculation showed that the volume of volatile salt was related to the volume of absorbed air as 1 : 9. Since, therefore, it is evident that true atmospheric air is compressed by the pore of bodies into much less space, then there is no doubt that *air given off from bodies, however much it surpasses them in volume, is true atmospheric air.*

§50

No differently from other bodies, *niter also has a great amount of air included in its pores.* Hales obtained 180 times its volume from this salt on distillation.[44] From gunpowder ignited in a vacuum Robins separated air which occupied a space 244 times greater than the powder itself.[45] On distillation there occurred a decomposition and separation of the particles from mutual cohesion, and hence the included air was liberated, but there rapidly followed also a reunion in

44. *Statica vegetab.*, ch. 6.
45. *Neue Grundsätze der Artillerie*, p. 90.

which the particles were condensed, fusing and, upon this again, absorbing air. On the contrary, on explosion of the gunpowder there is a decomposition of its particles without their subsequent reunion. This was evidently not because in the first case a less amount of air was observed than in the second. As for the reason by which the air enters in such great amount into the pores of the body, this is purely a physical question and hence not directly related. However, for the greatest enlightenment on this question we have considered separately our ideas on the elastic force of air.

§51

Considering that we have suggested in §48 and §49 the question just now raised: that all bodies contain such an amount of air held in the pores, and some a greater amount than niter, then why do they not have the same explosive force? However, it is easy to answer this question. Actually let us assume that one pound of wood and one pound of gunpowder are burned simultaneously; we see that the latter burns in about one second and the first burns in half an hour. Let us assume that the flame which continues for half an hour when the wood is burned is generated directly in one second; can we not compare this with the flame from nitrous powder? As the bullet of a gun, moving with the speed of one verst per hour, striking a wall, does not damage it, but when it flies the same distance in one second, destroys it, so sudden liberation of air produces a striking action which it will not give when liberated little by little. Therefore the strength of niter or nitrous gunpowder occurs from the sudden explosion of air liberated from the pores of the destroyed niter; this also happens in other bodies. What glass or other vessel is so strong that, being closed, it can resist the air generated on solution of iron filings in oil of vitriol? But this same oil, strongly diluted with water, dissolving an iron bar is incapable of producing any action of this sort.

§52

Thus it remains only to explain why niter combined with charcoal and sulfur in gunpowder explodes with such strength. But this can easily be understood if first we consider the nature

of the various component parts of gunpowder. These are the particles of sulfur which maintain the flame, the charcoal which disseminates the combustion, and the niter whose phlogiston, acting strongly in the acid, arouses the admixed sulfur, suddenly breaking down and giving birth to a flame of great strength.

THE END

Oration on the Use of Chemistry. Presented in a Public Session of the Imperial Academy of Sciences, September 6, 1751, by Mikhail Lomonosov

In 1749 Lomonosov was requested by the President of the Academy of Sciences to prepare an address in both Russian and Latin "on the origin and present state of chemistry." In that year he gave a speech on the name day of Empress Elizabeth, September 6, and so he was asked to prepare his speech on chemistry for the name day of the Empress in 1751. This he did, giving his "Oration on the Use of Chemistry" in Russian on September 6, 1751. The work was first published by the Academy as part of the record of the celebration of this day, and a Latin translation was prepared for the Academy by Lomonosov's student, Yaremskii, in 1752. A second Latin translation was issued as a separate publication by the Academy in 1759. The Russian text has been reprinted in *Collected Works,* II (1951), pp. 345-369, and in *Selected Works,* pp. 158-175. This rather bombastic oration is characteristic of the style admired in Lomonosov's day, and of which he was a recognized master.

In discussing the welfare of mankind, my auditors, I do not find that it is accomplished as if its benefits could be brought about by pleasant and simple labors. Nothing on earth can be given to mortals higher and more noble than an exercise in which beauty and significance, taking away a sense of wearisome toil, gather some delights which, while offending no one, entertain the innocent heart, and, increasing other pleasures, thankfully arouse perfect joy. Where can we seek such delightful, unblemished, and useful exercise except in science? Here we discover the beauty of multitudes of substances and the amazing variety of action and properties, marvels of art and order, constructed by the Almighty. Enriched by Him, no one then is harmed who gains for himself that inexhaustible trea-

sure given universally to all. In this work we find service, not for ourselves alone, but for all society and sometimes for all generations of mankind. How much all this is true, how many scholars by brilliant and careful labors have added felicity to our lives is clearly shown by the state of the inhabitants of Europe and that of those who endure wandering on the plains of America. Picture the differences of these two in your minds. Picture the one man who knows how to name only a few necessities of life which lie always before him, and the other who explains in his language not only everything produced by earth, air, and water, not only everything which has been given through many centuries, names, properties, and qualities but who can also express in clear and vivid words an understanding of what is not evident to our senses. The first of these men does not know how to reckon the number of his fingers; the other not only recognizes a weight through its size without a balance, but a size through its weight without a measure, not only can show from afar the distance of inaccessible objects on earth, but can also determine the awesome remoteness of the heavenly orbs, the vast spaces, the rapid motions, and in the twinkling of an eye a shift of position of these orbs. The one does not recognize a year of his own life or the short span of his children; the other not only locates by years and months a multitude of past times, existing in almost infinite relationships in nature and society, but also foresees many future events. The one, thinking that in the year of his birth heaven was joined with earth, worships wild beasts or great trees as divinities of his little world; the other, visualizing vast spaces, skillful structures, and the beauty of every living thing, with holy awe and reverent love worships the Creator of infinite great wisdom and strength. Consider the man who is scarcely able to cover his nakedness with leaves or the skins of wild beasts; and the one with clothes of cloth of gold, glittering with precious stones. Consider the one who for his defense from harm raises stones and trees from the earth, and compare him with the man with a supply of sharp weapons and machines which emulate thunder and lightning. Consider the man who can scarcely grind sharpened stones and thin trees with much sweat, and then the man who has powerful and skillfully made machines for moving tremendous loads, for hastening long drawn

out actions, and for exact measurement of size, weight, and time. Fix your eyes on the man who floats on an insignificant rivulet on a raft of bullrushes and on the man who dares the gulf of the sea in a huge ship, fortified by sure instruments; set him who moves against the force of the wind against him who without a pilot meets the rocky shoals.

Do you not see that one is placed almost above mortal destiny, the other is scarcely separated from the speechless beasts; one amuses himself with a clear understanding of pleasant radiance; the other in gloomy darkness hardly sees the existence of his ignorance. What great benefits does learning bring, how much enlightenment comes from human reason, how pleasant is the beauty of its enjoyment. I would wish to lead you into the splendid temple of human well being, I would wish to show you the penetrating wit and unremitting zeal of the wise and diligent men within it who devise the most brilliant adornments; I would wish to astonish you by the variety of novel changes, to cheer you with a delightful enumeration of the priceless benefits which they bring about, but it would require more of my understanding, more of my eloquence, more needed time for carrying this out than is allotted for the completion of this purpose. Therefore I beg you, follow me in your minds into just one hall of this great edifice in which I would show you some of the rich treasures of nature and explain the value and usefulness of those changes and phenomena which occur in chemistry. If in showing and explaining these, my words are anywhere unsatisfactory, the keenness of your own native wit will recompense you.

The knowledge gained by scholars is divided into science and art. Science gives a clear understanding of substances and discovers hidden actions and the reasons for properties; art applies this to the increase of human benefits. Science satisfies the innate curiosity rooted in us; art entertains by winning of profit. Science shows the path to art; art hastens the progress of science. Both together serve harmoniously for our advantage. In both of these, how great and how necessary is the application of chemistry is clearly shown by the study of nature and the many uses of art in human life.

On considering natural bodies we find in them two sorts of properties. One we understand clearly and in detail; although

the other presents itself clearly to the mind, yet we cannot picture it so completely and plainly. The first sort includes size, appearance, motion, and position of the whole body; the second includes color, taste, smell, medicinal strength, and many others. The first can be measured exactly by mathematics and can be defined through mechanics; with the other such details cannot be applied simply, since the first has as its basis bodies which can be seen and touched; the second, particles which are most subtle and far removed from our senses. Yet for an exact and detailed understanding of any substance we should know the particles of which it is composed. For how can we discuss the human body without knowing the composition of the bone and the manner of strengthening it; without knowing the joints and the position of the muscles for movement or the arrangement of the nerves for feeling or the arrangement of the viscera for preparing the digestive juices or the spread of the veins for formation of blood, or the other organs of this wonderful structure. Equally is it impossible to have a detailed understanding of the second sort of qualities mentioned above if we do not study their smallest and most inseparable particles from which they arise and whose understanding is so essential to the investigator of nature, since these particles are themselves so necessary for the composition of bodies. And though in the present century the device of the microscope has so increased the power of our sight that a scarcely visible mote can clearly show many parts, yet the power of this useful instrument serves only for study of organic particles such as the very small bubbles and tubules, invisible to the naked eye, which make up the solid parts of animal and plant substances; those particles of which mixed bodies consist cannot be seen individually. For example, it is known through chemistry that mercury is present in cinnabar and terra alba in alum, but neither the mercury in cinnabar nor the terra alba in alum can be seen through the best microscopes; the same form is always seen in them. Therefore knowledge of this can be attained only through chemistry. Here I notice you say that chemistry shows only the materials of which mixed bodies consist and nothing of the individual particles. To this I answer that truly at this time the sharp eye of the investigator cannot penetrate much further into the interior of bodies. Yet if any

such secret is discovered, chemistry will really be the foremost leader, will first tear away the veil from the innermost treasures of nature. Mathematics to some extent discovers the unknown. For this purpose, it composes the known from the unknown, it subtracts, it adds, it divides, it equates, it reduces, it transposes, it interchanges, and finally it finds the unknown quantity. Considering the case of the infinite and varied changes which the mixing and separation of the different materials of chemistry show, we should reach by reason the secret of the infinite smallness of form, measure, motion, and position of the primary particles which make up mixed bodies. When, distracted by love, a betrothed wishes to know the extent of attraction of his fiancée to him, in talking with her he notes the changes of color in her face, the turning of her eyes and the order of her speech; he observes her friendship, her amiability and cheerfulness; he tries to find out from the maid who serves her in her excitements, her dress, her visits, her domestic affairs; and so by all this he convinces himself of the true state of her heart. Equally the zealous lover of the beauties of nature, wishing to study deeply the secret state of the primary particles which make up bodies, must exhaust all those properties and changes, especially those which are revealed by her intimate maidservants and confidantes; when chemistry enters the innermost halls and when it gathers together the particles separated and scattered by solution into solid forms and shows the differences in their shapes, the student seeks to learn how this occurs by the use of careful and ingeneous geometry; when solid bodies are changed into liquids or liquids into solids, and the different sorts of materials are scattered or combined, he suggests answers by the use of accurate and intricate mechanics; and when, by the addition of liquid materials, different colors are produced, he investigates by penetrating optics. Thus, when chemistry spreads open the secret treasurehouse of which she is mistress before a curious and unwearied zealot of nature, who begins to measure by geometry, to expand through mechanics, and to observe through optics, then it is very probable that he will attain the desired secrets.

Here, I hope, you will still wish to ask why investigators of natural substances at the present time have not in fact succeeded so far. To this I answer that it requires a very skillful

chemist and a deep mathematician in one person. The chemist must not be one who understands his science from reading books only, but one who by his own art practices skillfully in it, and not on the contrary one who, although he makes numerous experiments, yet stimulated by a great desire for enormous and rapidly gained riches, hastens only to carry out his wishes and therefore, following his dream, scorns the phenomena and changes which occur in his work which serve to explain the secrets of nature. Nor is there need for a mathematician who is skillful in his work only in calculation, but there is need for one who in originality and demonstration is accustomed to mathematical strictness and can deduce the laws of nature from her exactness and order. Useless are eyes to one who wishes to see the interior of matter but lacks hands for opening it. Useless are hands to him who does not have eyes to see the substances opened. The chemist with his hands, the mathematician with his eyes can rightly be called physicists. But since both require help from the other in studying the inner properties of a corporeal body, on the contrary the human mind often withdraws along another path. The chemist, seeing in all his experiments different and often accidental phenomena and products, and enticed by this to the acquisition of rapid gain, laughs at the mathematician employed in some careful meditation on points and lines. The mathematician, on the other hand, sees in his propositions clear proofs and irrefutable and direct consequences which draw forth an unknown number of properties, and scorns the chemist as a practical man, overburdened and lost among many disordered experiments. Very much accustomed to clean paper and light geometrical instruments, the mathematician is choked by the smoke and ashes of the chemist. Therefore, at this time, these two, sisters bound by common advantages, give birth to sons who in great measure disagree. This is the reason that we do not yet have the full study of chemistry combined with a deep understanding of mathematics. Although in the present century some have shown fair success in both sciences, yet this enterprise is held to be beyond their strength and they do not wish to labor over the study of these particles with a firm purpose and constant zeal, especially when they observe that sometimes with no little waste of time and work, natural science is more

darkened by empty schemes born in someone's head than it is brought into the light.

The investigation of the primary particles which make up bodies is to be sought in the reasons for their mutual cohesion which joins them in the composition of bodies and from which all the differences in solidity and fluidity, hardness and softness, brittleness and ductility originate. How can all this be studied more fitly than through chemistry? Only chemistry softens them in fire and again hardens them, separates them, disperses them into the air and collects them back again from it, dissolves them with water and, evaporating it, strongly recombines them, dissolves solid bodies in caustic solutions and converts solid materials into liquids, liquids into dust, and dust into rocky solids. Thus curious physicists reveal a great many different paths to the great number of forms and infinite number of bodies by increasing or decreasing the mutual force of cohesion between the particles of the compound bodies which skillful nature has attained by her great art. But how wide and beautiful is the play of colors which investigators of chemistry have introduced into the field of nature which itself shows its action through such a multitude of colors, so different and useful. For copper alone not only produces all the pure colors which prismatic optical glass shows but also produces all sorts of colors when mixed under different conditions. The mixing and separation of other minerals and also of materials from plants and animals show in their changes bodies with properties pleasant to see. I cannot include everything in my brief words, but still, like some pantomime or a silent representation in the vast theater of nature these things make known to the astute observer their secret reasons by the variety of their changes, and seem to strive to give an explanation by their mute communication.

Animal and plant bodies consist of organic and mixed particles. Mixed substances are solid or liquid. Liquids are held by solids; solid bodies are nourished by liquids, they grow and bloom, they bring flowers and fruits. In the accomplishment of all this, nature changes the character of the juices in the different structures and organs; she especially changes the taste and odor, separates the sweet milk and bitter bile from a single food and from the same earth gives birth to acid and sweet

fruits and to herbs with unpleasant as well as pleasant odors. How many changes are produced in all this is well known to those who understand the structure of odorous bodies and the multitude of growing things of the earth. Chemistry strives in all these to imitate nature exactly; how often it softens strong tastes and develops weak ones; from lead, repulsive to the tongue, and sharp vinegar it produces a honey of surpassing sweetness, and by mixing minerals there is emitted the delicate sweet perfume of roses; on the other hand, from niter which has no odor or strong taste is generated the acidity which penetrates and corrodes solid metals and hinders breathing by its stench. Is it not clear from this that you cannot seek successfully the causes for different tastes and odors in any way other than by following this chemistry and using its art to divine in the fine vessels of organic bodies the locked changes sensible only to taste and smell?

A great part of physics and the most useful part of science for humans is medicine, which through an understanding of the properties of the human body reaches the causes of disturbances in health and, using proper media for its improvement, often restores almost from the grave those who suffer from disease. Illness in great part occurs from damage to the fluids which are needed for human life and are transformed in our bodies, whose qualities make up the parts which are beneficial or harmful in the changes which produce or cut off our capabilities and which no one can seek to study without chemistry. By it we understand the natural mixing of blood and the nutritive juices, by it we uncover the constitution of healthful and harmful foods, by it beneficial medicines are prepared not only from herbs, but from minerals taken from the depths of the earth. In a word, no physician can be complete without sufficient knowledge of chemistry, and in spite of all its flaws, of all excesses and of all the feeble intentions of those in medical science, chemistry alone offers hope.

For a long time it has been felt and stated in detail that chemistry has revealed and will reveal the secrets of nature. Therefore it is most important that I now explain this action to you. Fire, which for the measure of its strength is called heat, by its presence and action is so widely distributed in all the world that there is no place where it does not exist, for in the

coldest northern regions lying near the pole in the midst of winter it always can be demonstrated easily. There is not one action in nature which should not be ascribed to its basis, for from it all internal motion of bodies and hence all external motion proceeds. By it all animals are conceived and grow and move. By it blood circulates and our health and life are maintained. By its virtue mountains produce all sorts of minerals in their interiors, and waters spill forth, wholesome for weaknesses of our bodies. And you, pleasant fields and forests, you are covered with such beautiful clothing, you delight our members and cheer our senses when friendly warmth by its gentle advent drives away frost and snow, nourishes you with its rich moisture, speckles you with shining and fragrant flowers and enriches you with sweet fruits; except for this your beauty would wither, the face of the earth would grow pale, and the universe would be filled with lamentations. Without fire the nourishing dew and sweetly dissolving rain could not fall on the cornfields, springs would dry up, the course of rivers would be stopped, the air would lack motion, and the mighty ocean would solidify into perpetual ice; without it the sun would be darkened, the moon would be overcast, the stars would vanish and nature itself would perish. Therefore many seekers of the internal nature of mixed bodies not only wish to be called by the honorable name of philosophers acting through fire, not only did pagan peoples in whom science was held in great honor grant to fire divine worship, but also the Scriptures themselves often tell of divine appearances in the form of fire. Thus among natural substances, what is more worthy of our study than that common spirit of all compound substances, that which gives birth to all the wonderful changes within bodies, that sensitive and strong instrument? But it is not possible at all to undertake this study without chemistry, for what can more know the properties of fire, can measure its strength and can open the way to the secret causes of its actions than chemistry which carries out all its enterprises by fire? Without using ordinary methods, it suddenly produces fire in cold bodies and great cold in warm ones. It is known to chemists that strong waters which dissolve metals without contact with external fire are heated, boil, and give off a burning vapor, that by mixing together strong acid of niter and some fatty ma-

terials not only is there terrible boiling, smoke, and noise, but also a violent flame which enflames the eye in an instant; and contrary to this, warm niter, put into warm water, gives such a strong cold that in a suitable vessel in midsummer it freezes. I do not mention here the different phosphors prepared by chemical art which in the open air catch fire spontaneously and so are related to the above effects; they show that the properties of fire are not studied by anyone as suitably as the chemist. No one can approach closer to this great altar, kindled from the beginning of the world by the Most High, than this most closely related priest.

This is the use which physics gets from chemistry. This is the method by which a clear understanding of substances illuminates and shows a direct path to the artist, and in this science I shall now try briefly to show how useful and how strong it is.

Among the artisans the first place, in my opinion, is held by the metallurgists who seek to find and purify metals and other minerals. This advantage is given to them not only by their great antiquity, as the Scriptures testify,[1] and by the agreement of all sorts of humans, but also by the great and widespread use of the metals themselves. For metals give strength and beauty to the most important substances in common use. They decorate the temples of the gods and adorn royal thrones, or, protecting from enemy attack, they maintain ships, which bound together by the strength of metals, float safely on the ocean depths among stormy gales. Metals open up the depths of the earth for the enrichment of the soil; metals serve us in capturing land and sea animals for our sustenance; metals facilitate coinage for the convenience of merchants who thus avoid the use of wearying and heavy goods. And to speak briefly, not one artisan, not one craftsman can avoid the general use of metals. But these so necessary materials and especially those which have greater utility and value encourage us to work deep in the earth, although they are often changed in external form. Precious metals mixed with simple earths or combined with base rocks escape our eyes; on the other hand, simple substances present in small and unprofitable quantities,

1. Genesis, chapter 4.

and material which shines like gold and shows various and beautiful colors may lead on the unskillful to hope of great riches. And although sometimes the unskilled happen to find and recognize precious metals in the mountains, yet this is of little use to them when they do not know how to separate from them the undesired substances, or, having separated a large part, waste it by lack of skill. In this case, how penetrating and strong is the action of chemistry! In vain does cunning nature hide her secrets from it by such a base screen and shut them up in such simple shrines, for the acuteness of the fine fingers of chemistry knows how to recognize the useful as opposed to the useless, the precious as opposed to the base, and to separate them and to see through the false surface to the inner worth. In vain does she lock up her riches in the hardness of heavy rocks and surround them with materials harmful to our lives; for armed with water and fire, chemistry breaks down the strong covering and drives away everything which is contrary to health. In vain does she surround this golden fleece with the mouth of such a fierce and terrible dragon, for the seeker, taught by our gentle Medea, draws out the venomous teeth and guards the medicine taken from them with the entwined vapors. These benefits began from chemistry and in our fatherland are carried out as they were in Germany, about which the ancient Roman historian Cornelius Tacitus once spoke.[2] "I cannot say," he wrote, "that silver and gold are not born in Germany, for who tries to seek them there?" And as there in the following centuries great riches were found, as was shown in the Meissen and Hartz factories, so also in Russia we should hope for the same and gain obvious benefits from this by sufficient experiments. It is not true, as they say, that in warm regions there are more precious metals, born by the action of the sun, than in the cold, for according to true physical experiments it is known that the heat of the sun does not penetrate to those depths in the earth in which metals are found. And burning Libya, which lacks metals, and bitterly cold Norway, which has pure silver in its rocks, are shown to be opposed to this opinion. The only difference is that in hot countries the metals lie closer to the surface of the earth, for which reason

2. *Germania,* chapter 5.

they can be clearly seen. First of all, great rains often fall there and in some places continue for half a year, softening and carrying away the soil and washing away the light, leaving the heavy minerals; therefore the inhabitants of that place after the rainy part of the year always seek in the proper place for gold and precious stones. Secondly, parts of the earth are shattered by earthquakes, and mountains are shifted and those things which nature produced within the earth are thrown out on its surface. Thus it follows that it is not the greater amount of metals, but their easier availability that allows the hot countries to gain the advantage over us. Spacious and abundantly supplied Russia requires zeal and labor to seek for metals.

It seems to me I hear her prophesy to her sons: Expand your hopes and reach into my depths, and do not think your search will be in vain. Give to my fields the work of the cultivator and my fertile soil will multiply your flocks and my forests and waters will be filled with animals for your nourishment; all this will not only satisfy needs within my borders, but will overflow in its excess into foreign countries. Can you therefore think that my mountains will not reward the sweat of your brow with rich treasures? Within my borders from the heat of India to the Arctic Sea you have evidence enough of my subterranean wealth. For the things needed for these deeds I open to you in summer my far flowing rivers, in winter I lay down my smooth snow. From these labors of yours I expect increase of merchants and artisans, I expect greater degrees of adornment and strengthening and increase of armed forces, I expect and wish to see the expanses of my seas covered with multitudes of fleets, terrible to the enemy, and the glory and strength of my empire extended over the deep to strange lands. Rest easy over this, blessed country, rest easy, our dearest fatherland, when in thee such a generous patroness of science reigns. Thy great enlightener founded and increased the defense of solid metals; his most august daughter has followed her father and increased their value for thy ornamentation and enrichment, and has expanded along with other sciences the chemical art which, affirming her maternal care of this great empire and encouraged by her generosity, has penetrated into the mountains and purified that which lay dormant and useless within them for the increase of our happiness and above all, by power-

ful metallurgy, has striven to bring thee other useful materials.

The hands of chemistry are widely spread in human affairs, my auditors. Wherever we look, wherever we search, do we not everywhere find before our eyes the success of its enterprises? In the earliest times of the formation of the world, man was forced by heat and cold to cover his body; at first using leaves and skins, he then learned to make himself clothing from wool and other soft materials, clothing which, although it protected his body sufficiently, yet by its changeless form wearied the human heart; his changing desires required differences; he shunned the simple whiteness and, envying those animals which were multicolored, he sought to protect his body with like splendor. Then chemistry, squeezing out juices from herbs and flowers, extracting roots, dissolving minerals, and combining different substances with each other, strove to carry out the wishes of mankind, and how much it has adorned us thus does not need my words and proofs, but you may see it everywhere with your own eyes.

These chemical devices not only give cheer to our gaze by variety in garments, but also satisfy other needs. What can produce greater zeal and respect in us than our parents? Who is dearer in life to a man than his own children? Who are more pleasant than sincere friends? But they are often absent in distant places or have departed from the light of our eyes. Under such conditions what can comfort us more and soften the sorrow of our hearts than their likenesses, painted by the art of portraiture? The absent are made present and the dead brought to life. Everyone who has long departed or is separated by space from our sight is brought close to those who gaze upon the painting. Here we see before us great rulers and brave heroes and other famous men, worthy of glory among their descendants. We see far off in distant lands great cities and huge and magnificent buildings. Turning to distant fields or between high mountains we gaze for a time in silence on the stormy ocean, on the shattered ship or on one brought by the power of the wind to the sheltering shore. In the middle of winter we are delighted by the sight of a green forest, a flowing spring, grazing herds, and laboring farmers. All this we can see through painting. But this depends entirely upon chemistry. Should we take away the means for preparing pigments, we

would be deprived of the pleasures of portraiture; likenesses are lost along with these substances and the very vividness which we gain from it disappears. It is true that the pigments do not retain their brightness and goodness as long as we would wish, but in a short time darken and finally the great part of their color disappears. To what shall we turn to escape this difficulty? Who can invent a long lasting medium which will last for the artist? That same chemistry which, seeing that the delicate compositions fade and are destroyed by the changes from air and sunlight, by the strongest weapon of its art, using fire, and combining solid minerals with glass at a great heat has produced materials which in color and purity greatly excel, and in hardness and resistance to moist air and the great heat of the sun assure that through many centuries their color will not be lost, as is shown by the mosaics, more than a thousand years old, found in Greek and Italian temples. And though in ancient times natural rocks of different colors were used for this purpose, and for ordinary painting different natural earths served for the unchanging pigments used in art, yet the great advantage which glass compositions have over stones at the present time attracts us to the art of the Roman artisans and its use. For, in the first place, rarely and with great difficulty can we obtain the shades of so many colors from natural rocks to put into the compositions desired by the artist. Second, though sometimes they are arranged with great difficulty, not a few precious stones suitable for other uses may be spoiled. Third, it is possible to prepare for the compositions parts of a desired size and shape because of their great softness and easy melting, while for natural stones great labor and patience are required. Finally, glass colored by art is much superior to the color of natural stones, and in the future will attain to great perfection by the art of the chemist. It is true that stones surpass glass materials in hardness, but this is unimportant in matters in which resistance of the colors to air and sunlight is required. Thus, it is not in vain that modern master craftsmen prefer art to nature in this matter, since art requires less labor and produces a better result. Since there is already one use of glass in the painters art, it is scarcely likely that there will not be many faster and better uses stemming from this great chemical discovery. But discussing it requires a whole new vocabu-

lary which has no place here. Therefore I hurry on to other actions which our science shows by its art.

But what vast expanses do I see before me! I see still other substances which draw my words onward. And when I wish to show you how much chemistry grants us in the preparation of pleasant food and drink, the discussion must be preceded by consideration of the vessels in which we enjoy these. We imagine their purity, transparency, brilliancy, and varied colors by which the art redoubles the sweetness of taste, satisfying alike to the tongue and the eye. Now I do not wish to tire your patience by the details of all I have mentioned, but I will conclude with one salutary boon to mankind which chemistry has granted.

How sad were adventures and conquests in ancient times and different lands and how often we read with pity the history which tells of distant and unknown countries when these were suddenly invaded, great and glorious cities were turned to smoke and ashes, villages were laid waste, and whole peoples who did not have time to resist the rapid attack were finally destroyed and scattered, so that of their great power and glory only the name remains. We read of filling fields with many thousands of wounded and wide rivers of blood and piles of corpses, which surpasses the happenings of our time, in which we do not have such horrible events. Yet the concern of notable writers and the very ruins of ancient cities dispel doubt as to the truth of these sad and shameful occurrences. From whence do we see the establishment of moderation among mortals? Did Orpheus by his sweet singing soften the temper of mankind? But in the present century we still have wicked and envious persons who sadden the heart by stealing the possessions of others. Did Lycurgus or Solon by stringent laws bind the passions? But now we often respect strong weapons above the rights of nations. Did the mighty and ancient Croesus with his surpassing wealth sate the greed for money? But this is like a flame: the more fuel is added, the stronger it becomes. Who has given us such a great boon? A simple and poor man who, to escape his poverty followed chemistry at a distance to obtain wealth by a new road and in this intention opened a path into the inner ways of metals; he combined sulfur and niter with charcoal and placed them in a vessel on the

fire. Suddenly a terrible sound and a strong blast occurred! And though he himself did not remain unharmed, yet great was the glad hope that he had obtained a strong material for attacking insoluble metals. Therefore he closed up and riveted his composition in a solid iron vessel, but without success. From this came firearms thundering at troops and city walls, and from the hands of human beings deadly lightning flashed.

But, you say, this does not revive; it kills, causing further and stronger blasts. I answer, the more it saves. Consider a battle of warrior against warrior, sword against sword, blow against blow in closest contact; would not many thousands of beaten and wounded fall to death in one moment? Compare this with the present battles and you will see that the hand can strike down much faster than the gun can be loaded with powder and metal; it is easier to strike in inflicting injury in the clear air than through thick smoke from distant guns; more brightly blazes the heart in a confrontation which can be seen directly against itself than when this is hidden. Here is the reason that in the present century there is no Hannibal like the one who took from the Roman nobles killed in one battle four measures of gold rings. There is no inhuman Batyev who, proceeding in a short time from the Caucasus to the Alps, is believed to have laid many lands to waste. There is now no foreign enemy to trouble our quiet nation; but men fear that the building up and supplying of these new inventions, preserving their strength, will deprive us not only of profit, but of life itself. On the contrary, what has the power to destroy such fortifications, other than the inventions of chemistry: compare an army on a long march, burdened with heavy equipment, and the rapidly arriving news of the misfortune and the announcement calling the nation to the defense. Thus chemistry, by the strongest weapon, lessens the destruction and the threat of death to humanity and delivers many from slaughter.

Rejoice, populous places, adorn yourselves, impassable deserts, your happiness approaches. Tribes and nations will surely increase and will be scattered more rapidly than before; quickly great cities and rich villages will adorn you; instead of fearing wild beasts your spaces will be filled with humans who please the eye; instead of thorns, grain will cover you. Then do not forget to give thanks to chemistry for your good fortune and

encouragement, for it asks nothing of you but diligence in its practice for your greatest adornment and enrichment.

In discussing the uses of chemistry in science and art, my auditors, I should warn you that I do not consider that all human life consists in this one study and that I regard with contempt those amateurs who do not consider the needs of other arts. Each science has an equal part in our good fortune, and you have heard of several at the beginning of my oration. The human race should render great thanks to the Almighty for the gift to it of the ability to obtain such knowledge. Most of all should Europe render thanks which most of all enjoys this gift and is thus distinguished from other nations. But how fervent is the zeal of Russia which can place its offering on the altar at a time when science, after the darkness of barbarian centuries, has begun to shine forth, raising in its great wisdom a hero, the great Peter, the true father of his country who took Russia, so long removed from the light of learning, by his manly hand and, surrounded on all sides by enemies internal and external, was protected by the gift of God; he destroyed all obstacles, and set it on the path of clear knowledge. At the end of his heavy military labors, having strengthened the safety of the whole fatherland on all sides, he first of all took care to establish, to assist, and to augment science in it. Blessed be those eyes which saw the majesty of this man on earth. Blessed be those who sacrificed, who poured out sweat and blood for him and for the fatherland and who after loyal service were anointed by a kiss on head and eyes.

But we, who were unable to behold the mighty father in life, now have the great comfort that we see on the throne his daughter, so worthy of her father, his successor, our most gracious empress. We see the pious daughter of the God-fearing father, the courageous daughter of the heroic father, the sagacious daughter of the all-wise father; the father a founder of science, the daughter its most generous patroness. She regards science with maternal care and with devoted zeal she wishes that during her blessed life and in her fortunate domains there should be not only a meeting place, but also a happy life for its own learned sons.

An Attempt at a Theory of the Elastic Force of Air

Lomonosov was always interested in explanations of physical phenomena in terms of his corpuscular theory, and though most of his early work had a more strictly chemical character, he never failed to note the physicochemical implications of his theories. Thus, when in 1748 he was planning his essay on the nature of niter, he ascribed the explosive power of this salt to the presence of large amounts of air in its pores, and so he was led to a consideration of the elastic power of air. The results of his thinking were presented to the Academy of Sciences on September 2, 1748, and were published in the group of his papers which appeared in 1750. His Latin manuscript "Tentamen theoriae de vi aëris elastica" was published in *Novi Commentarii Academiae scientiarum imperialis Petropolitanae,* 1:230-244 (1750). It was translated into Russian by B. N. Menshutkin in 1936. The Latin text and Russian translation were reprinted in *Collected Works,* II (1951), pp. 105-139, and the Russian translation is given in *Selected Works,* pp. 134-149.

§1

After the use of the air pump had been made well known, the natural sciences received an enormous development, especially in the part treating of the nature of air. The properties of the latter, entirely unknown in the last century, are now not only familiar to us, but are even expressed in mathematical laws, and we see with admiration that they have reached almost the highest degree of clear comprehension. But, although in the reports of physicists its elasticity is described more often than the other properties of air and to everyone who undertakes the study of natural science it is presented as one of the chief factors in natural phenomena, yet the reason for it remains insufficiently explained and even famous investigators have taxed their inventiveness in vain for its explanation. Therefore writers on physics in great part do not touch upon the reason for elasticity, but are satisfied merely to describe its action. Even if anyone gives a reason, he has under him only

precarious support which is not enough to explain the effects caused by elasticity of air. In great part, then, these reasons already lack significance, since they contain in themselves nothing except questions merely changed into other words.

§2

Of all the suggestions for explaining the elasticity of air in hypotheses which have been made known to us up to now in the papers of physicists, it seems most realistic to start from the central laws of motion, for in them there is no question of varied phrases for the cause itself, and nothing foreign to the laws of motion is suggested. In taking up this matter we would only have repeated what has already been done if we did not see that in the outstanding discoveries made up to now there are some deficiencies, or, more truly, superfluities.

§3

Actually, we consider it superfluous to call for the aid of some strange fluid in finding the reasons for the elasticity of air, a fluid like that which many, according to the usage of this century, so rich in subtle substances, customarily employ for explaining the nature of phenomena. We are satisfied with the subtlety and mobility of the air itself, and seek the reason for its elasticity in its own material. Everyone who has read our meditations on the cause of heat and compares what follows with it will agree that we can safely do this.

§4

So as to set about this task in proper order we begin with a clear presentation of the idea of the elasticity of air; therefore we propose this reasoning as certain and say that the elastic force consists in a tendency of air to distribute itself in all directions. Hence we conclude that the insensible particles of air, which mutually recede from each other, actually expand as soon as any obstacle is removed. Thus we come to consider two matters: the nature of the particles themselves and the force by which they are separated from each other.

§5

The particles of air can be considered in two ways: either as separate particles of a complex body such that from their

known state and organized structure the particles which form them tend to expand and thus each separate particle can expand into a great space and be compressed into a smaller one; or the property of elasticity can be shown not by the physical composition and organized structure of the individual particles, but by their combinations.

§6

The first assumption, which is contrary to the greatest simplicity of nature, also does not agree with the transparency and indestructible stability of air. For in all compound and organized structures there should be particles which the force of heat excites more and more, with production of greater elasticity. Therefore, when air is rarefied by the sun's heat, the rays of the sun should certainly penetrate into any particle. And since in descending from any surrounding ethereal fluid (or, if you prefer, from a vacuum) the rays must everywhere pass through solid particles which settle down and hence are specifically much heavier, an infinite number of times; this cannot occur unless on entering and leaving each particle of air they will undergo refraction. And although in particles of such a nature the refraction may be infinitely small, yet the refracted light in an endless number of particles from the surface of the atmosphere to the earth itself would be so weakened that we would come to be in perpetual night. This is confirmed by similar cases: particles or molecules of water, consisting of combinations of its atoms, form clouds, and although each particle refracts light slightly and separately and in a small space does not nullify the transparency of the air, yet when these are collected more thickly and deeply, they darken the sky with blackness and sometimes almost completely prevent use of the light of noon.

§7

Finally, we take into consideration the numerous changes undergone by the air, its especially rapid motions, very strong impact, very great friction with very solid bodies, and the pressure of the atmosphere, and we remember the experiments of Roberval who kept air strongly compressed for 15 years and at the end found its elasticity unchanged; then it is im-

possible to assume that the separate particles of the air, so minute, will be organized or consist of many particles of incomprehensible smallness, very mobile and therefore bound to each other very slightly. Therefore we accept the second assumption of §5 and in no way doubt that *those particles of air which produce elasticity, tending to separate from each other, lack any physical complexity and organized structure,* and in order to be able to undergo such changes and to produce such remarkable actions, they should be *especially stable and not undergo any changes*; therefore in truth we ought to call them *atoms.* And since they act physically on material bodies, they themselves should be corporeal and have *extension.*

§8

As to the shape of the atoms of air, we consider that the mobility, stability, simplicity, and very soft nature of air leads mostly to a shape very close to spherical: this we deduce with full clarity from the findings on the reflection of air from ellipticle arches. Since, further, hot air heats cold bodies which it surrounds, this signifies that its atoms excite in particles of bodies which touch it a rotary motion[1] which also produces heat. And this can occur only if friction arises between them; but friction can arise *only if the atoms of air are roughened.*

§9

However, this idea agrees to the greatest degree with the nature of the material. Actually, in all the bodies of the world, either taken as a whole or in their parts, shape is distinctive for each but they are never so leveled that they do not show some irregularities. However, these latter are so present that, due to their very small ratio to the whole body, the shape itself retains its individuality. Just as nature for her needs made our earthly globe mountainous, and she made even the smoothest seeming particles of the bodies belonging to it rough and uneven, just so then we conclude by analogy that the aerial atoms also, though they have no physical complexity, are sup-

1. See our Meditations on the Cause of Heat.

plied by the care of this same nature, skillful in its simplicity, with very small and very strong projections for the production of very useful actions.

§10

But the atoms of air, showing elasticity, move away from each other either by some direct reciprocal action or by means of some fluid which separates them and therefore is formed of much smaller particles. We will now discuss which of these two possibilities produces the elasticity. For this we consider one of the chief properties of the elastic force of air, namely, that the more the air is compressed by external force and the closer the atoms come to each other, the more elastic force is excited.

§11

We assume first that the particles of air are dispersed to different sides by the action of some especially subtle fluid which is located between them. When air of any sort of solid vessel is compressed into less space, then this fluid is either compressed along with it, or it is not compressed. In the first case: 1) the walls of the solid vessel will be impervious to the very subtle fluid, and hence its particles will be hardly or not at all smaller than the atoms of air, which contradicts what was said in §10; 2) this fluid will itself act on the vessel which contains it; then it evidently is not required that the particles of air will intermingle with this fluid, since it is sufficient for producing the action of elasticity with respect to the body by itself; 3) its particles will have a tendency to withdraw from each other so that it will again become necessary to explain this, and finally, the question being considered will remain unanswered. In the second case: 1) this fluid will scarcely produce any action on the walls of even the strongest vessel and hence on the finest atoms of air, easily avoiding by its lightness and mobility all the forces which could act upon it; 2) when compressed in a vessel, the air is thickened and the density of the fluid which already easily passes through the walls of the vessel will remain the same so that the number of air atoms with respect to the amount of fluid becomes greater than before the compression. Therefore the elasticity of the fluid,

whose amount is made less, will exert less effect on the air atoms and hence the elasticity of the air, compressed by an external force into less space, should be lessened.

§12

All this shows very clearly that the force of elasticity of air cannot come from any fluid which separates its particles. And since this force, other conditions being equal, is increased or decreased proportionally to the density of the air material itself, there is no doubt that *it is produced by some sort of direct interaction of its atoms.*

§13

One body cannot act directly on another without contact with it; therefore when atoms of air act directly on each other they must necessarily come into contact. Further, since our atmospheric air under the influence of an external force can be compressed into more than thirty fold less space, there must exist between the atoms spaces not filled with their own material and in these spaces many such atoms can be put; hence the atoms are not found in mutual contact. At first glance, these two facts seem contradictory, but nonetheless they are very true and cannot be otherwise reconciled than by distinguishing two contradictory states of the atoms of air with time, so that atoms occur in one or another state alternately. The alternation must be of such a nature that not all the atoms should simultaneously show the same state, and that a given state should not last for a perceptible time. For the first would sufficiently often cause striking changes in amplitude, and the second would make expansion of the air especially slow and sluggish. Evidently therefore the separate air atoms in disordered alternation collide with the nearest in an insensible interval of time and while some are in contact, others are torn one from another and strike those nearest them, so that again they rebound; thus, continually repelled from each other by frequent mutual blows, they tend to scatter on all sides.

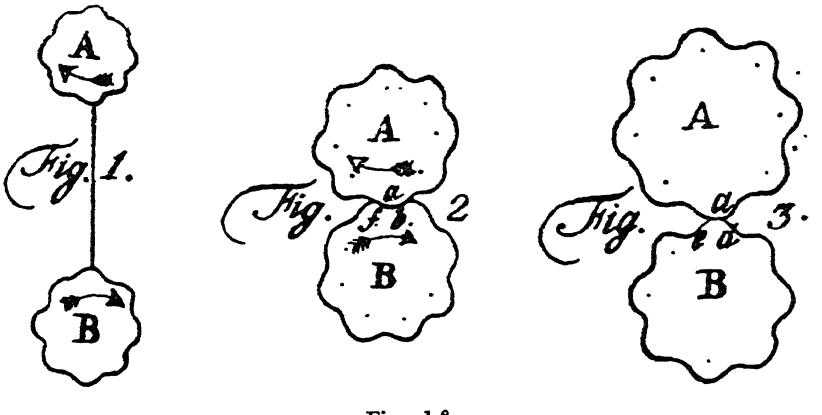
§14

Having established all this, it remains for us to show how air atoms so react with each other that one atom repels

another. No other argument can be presented than the most important property, this same elasticity of air. Namely, as each person knows, when the heat of air increases, its elasticity is more and more strengthened, and when the heat is decreased, it is weakened, so that, other conditions being equal, the greatest elasticity is found with the highest heat known to us, and with the least heat, that is, at the greatest cold examined up to now, elasticity is lowest, according to a constant law. Hence it is evident that the atoms of air act reciprocally on one another by contact more strongly or more weakly depending on increase or decrease in their degree of heat, so that, if it were possible that heat of the air entirely vanished, then the atoms should be completely lacking in this interaction. Hence it follows that *the interaction of atoms of air depends only on heat.*

§15

Heat consists of a rotary motion of the particles of the hot body[2] because everything which produces heat causes a rotary motion of the particles of the heated body so that the interaction of the atoms of air depends on their rotary motion. But two spherical bodies, perfectly smooth, placed next to each other and brought into very rapid rotary motion, cannot interact so as to repel each other. Thus, here there is once more confirmation of the truth presented above (§8), and we see the



Figs. 1-3

2. Meditations on heat.

ingenuity of nature, which very often by one and the same means produces different effects in bodies, so that here the roughness of the atoms of air serves to transfer their heat to other bodies (§8) and to bring about elasticity.

§16

Thus, let two atoms of air *A* and *B* be separated from each other so that atom *A* is above atom *B* (Fig. 1). Let both rotate very rapidly, so that part of the surface of atom *A* facing atom *B* moves in a direction opposite to that in which moves the part of the surface of atom *B* facing atom *A* as the arrows show. Let atom *A* at the time of rotary motion fall by the force of gravity on atom *B*; at their contact the irregularities agree in such a way that either projection *a* on atom *A* falls in the hollow *b* of atom *B* as in Fig. 2, or it will be on projection *d* of atom *B*, as Fig. 3 shows. In the first case the projection *a* of atom *A* on rising from the hollow *b* should ascend projection *f* of Fig. 4 so that atoms *A* and *B* recede from each other through a distance *gf* or *ab* in that insignificant period of time in which the oppositely tending directions of these surfaces of atoms *A* and *B* pass over the arc *ga*. In the second case the atoms at the point of contact proceed beside each other until projection *a* of atom *A* falls into the hollow *c* of atom *B* (Fig. 3). Then indeed everything follows as it would in the first case.

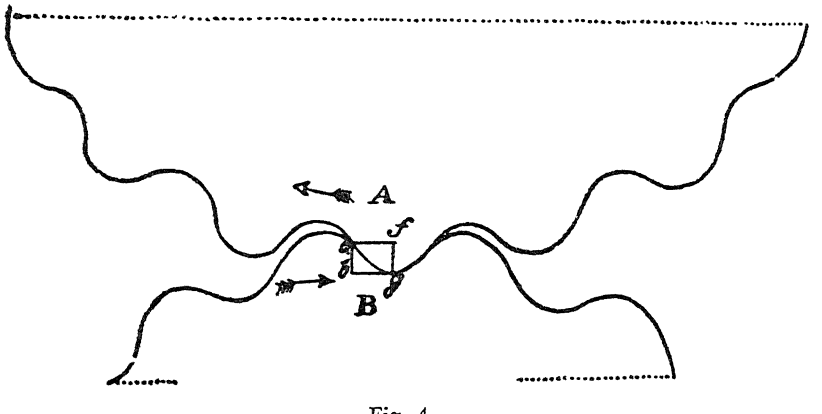


Fig. 4

§17

In this arrangement, since the separate atoms of air have weight, then by the force of gravity one atom will necessarily

fall on another. Being in rapid rotation the atoms after contact at once fly apart from each other as explained in the preceding paragraph. However, since with a great quantity of atoms it cannot happen that each will fall on an upper point of the surface of the lower atom, therefore because of their repelling action they will most often fall on lines more or less inclined to the horizontal, and thus the force of elasticity will be displayed in all directions.

§18

The interaction of atoms is also illustrated by the gyroscope with which boys play on ice. Actually, two such gyroscopes, put into very rapid rotation, when they slowly approach one another, after contact rebound very rapidly; this repulsion comes from irregularities on their surfaces. The more irregular these surfaces at the point of contact, the more rapidly will the gyroscopes rebound. This can occur between two gyroscopes three or even four times before their rotation is stopped and they fall; this occurs if they cease to be put in motion by the whip.

§19

Although the theory we have suggested is supported solidly enough by reason, yet the evidence will be still clearer for us if by its help the particles of air and the effects found in them can be so explained that their reasons will be presented plainly and with full distinctness. Just that theory is best which not only does not contradict any property of the substance for whose explanation it has been proposed, but by explaining those properties is used as the most convincing evidence confirming them; therefore in what follows we will examine our theory, analyzing the most important properties of air and the different effects arising from them.

§20

The atmosphere consists of an infinite number of atoms of air of which the lower repel those which lie above them, as many as all the other atoms piled up on them right to the upper surface of the atmosphere. The further the atoms are from the earth, the less will be the force of the atoms pushing and weighing upon them which they meet in their upward course, so that the upper atoms occupying the very surface of

the atmosphere are carried down only by their own weight and being repelled from the next lower ones are then carried upward as long as the impact received from the repulsion exceeds their own weight. But when the latter prevails they again fall down, so that they will be repelled by those found lower. Hence it follows: 1) that atmospheric air should be rarer, the more it is separated from the center of the earth; 2) that air cannot be infinitely rarefied, for there should exist a limit where the weight of the upper atoms of air exceeds the force received by them from mutual collisions.

§21

The faster the surfaces of the atoms of air *A* and *B* slide over the arc *ag* (Fig. 4), the faster will the atoms themselves pass through the distance *ab* or *fg*, receding from each other, and therefore they will acquire the more speed from the repulsion the more strongly the resisting contact of the body acts, and thus they will be separated further from each other by the rebound. And since the more rapidly the surfaces move, the faster will be the rotation of the atoms of air themselves, and as the rotary motion is increased, so will be the heat,[3] so that it is not surprising that warmer air has more elastic force.

§22

Finally, experience shows that the highest degree of cold found in winter in countries to the northwest is surpassed by the severity of winter in our region, and this in turn yields considerably to the severity of the frost in the Yakutsk region which binds almost all fluids except air. This discussion leads us to the conclusion (as is shown in our Meditations on the Cause of Heat and Cold), that nowhere on our earthly sphere can there be absolute cold, and therefore nowhere is the rotary motion of atoms of air ever fully stopped, and nowhere, evidently, can air be found without elasticity.

§23

Sound is produced when some body, set in vibratory motion, imparts this motion to the air particles next to it and these

3. Meditations on heat.

transfer it in a continuous series to the following ones to a distance proportional to the strength of the blow. Since most atoms of air are not in contact with the distant ones, it is necessary that each, in order to excite the motion of sound which is received from the sounding body in another, should first approach the other atom and most of all communicate to it a blow expending motion on it in an infinitely small time. These infinitely small time intervals with an almost infinite number of atoms by successive transfers to much greater distances require a considerable interval of time. And hence it follows that sound after a blow which produces it will be heard afar off after a marked interval of time.

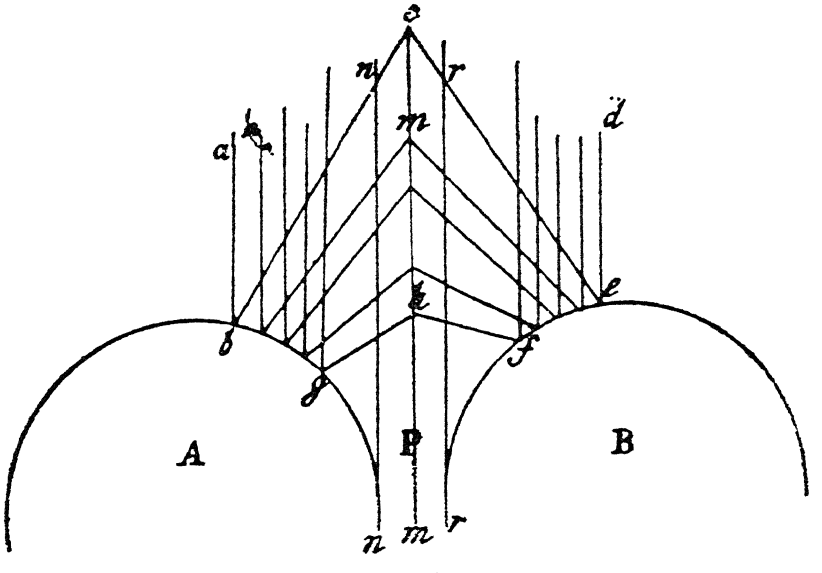


Fig. 5

§24

When air produces pressure on the surface of any body, the pores of which are larger than the atoms of air but have a diameter less than the space which is ascribed to the vibrating atoms, then the atoms of air, due to repulsion, should receive their own motion around the opening of the pore. Thus (Fig. 5) let *P* be the pore falling between particles *A* and *B* on the surface of a solid body or even a denser liquid where the air is located; let some atom of air strike the particle *A* from *a*

onto *b* and rebound from it to *c* so that it cuts the line *mm*; let another atom of air strike thus on particle *B* from *d* onto *e* and rebound to *c* so that the line *ec* makes the angle *bce* with line *bc*. Finally, let other atoms of air strike at points on the surface of one or the other particle closer to the pore *P* at *f* and *g* so that, rebounding from these particles they describe in their paths lines forming angles the apex of which, *h*, projects out from the pore as shown by the lines *fh* and *gh*, and others are shown more removed from pore *P*; then all the atoms of air which move in the direction of these lines by joining and proportionally to the area should repel with great force other atoms directed into the pore between the lines *nn* and *rr* and obstruct the entrance designated by these lines. All this is concerned with those atoms which fall perpendicularly to the plane of the body, but many, almost all the atoms of air which strike at an oblique angle, must of necessity produce a similar effect. Actually (Fig. 6) let an atom of air strike particle *A* from *a* to *b*; it rebounds from it to *c*. Then let another atom strike the same particle from *d* to *e*; it rebounds and strikes particle *B* at *f* and finally is reflected in the direction to *g*. Both of these, however, will create pressure against atoms of air directed straight into the pore. Therefore it is not surprising that air scarcely or not at all penetrates the many bodies whose pores, as shown by other results, are larger than the atoms of air. Finally it is evident that air is kept the more strongly from penetrating into the pores of a body the more the lips are separated, as is easily understood from the figure.

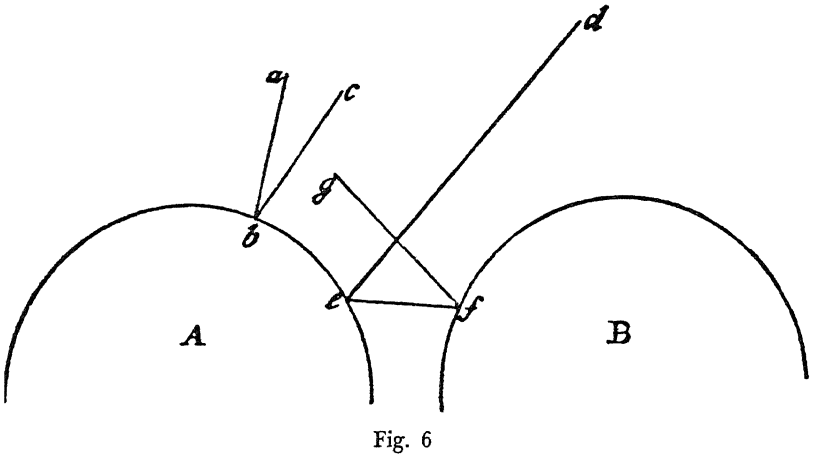


Fig. 6

§25

Sound is propagated by vibratory motion of atoms. But according to our theory, elasticity consists of the same sort of disordered motion; therefore we can ask why we do not hear a continuous sound from the continuously vibrating atoms of elastic air. To this we answer that sound comes to the ear through the eardrum, set in motion by the force of air; when it is at rest this does not occur. But since the eardrum undergoes the action of the same vibrating air from both sides, air which fills the cavity which the eardrum closes both externally and internally, then, being in equilibrium it does not vibrate by any motion, and a sensible sound is not impressed on it. But when this equilibrium is destroyed, there arises motion of the eardrum and a sound is heard. Therefore if we bring to the ear a solid, hollow vessel, then the vibrations of the atoms of elastic air, rebounding from the walls of the vessel, are concentrated and react on the eardrum more strongly than the blows of the atoms enclosed in the inner cavity, thus setting the latter in motion and communicating to the ear some confused sound. Since this sound is always perceived if we bring to the ear a concave object, it is evident that in elastic air the atoms are continuously moved by a vibratory motion.

§26

Air can remain elastic as long as there exists a reason for the elasticity, that is, reciprocal blows of the atoms. On the other hand, if this action for any reason stops, then by necessity the elasticity of the air should be nullified. Therefore if the atoms of air singly or several together are so held in the space between the strongly cohering particles of a body that they can neither destroy the cohesion of these particles nor act mutually on each other, then certainly that air should lack elasticity. On the other hand, if the cohesion of the particles stops for this body, then the atoms of air leaving by themselves regain the property of elasticity. And if the particles of the body which keep the air captive in the pores have a less diameter than those spaces through which the atoms of air run at each vibration, then the air liberated from the pores expands into a greater space than is occupied by the body in whose pores it was concealed.

§27

All this already long ago was in fact discovered by the illustrious and most deserving in science Robert Boyle, Hermann Boerhaave, and later the illustrious Hales; they all without exception called air a subtle and elastic material obtained from the solution of bodies. And we ourselves carried out many such experiments, especially those where on solution of copper in aqua fortis we obtained a great amount of elastic fluid which we recognized as true air. For in a vessel where this fluid was collected we put fixed alkali in the form of a strong water solution which absorbed the brown vapor filled with subtle acid which rose continuously on solution of the copper; to this some authors who feared to call the regenerated air by its true name and preferred to speak of some sort of "gas" ascribed the elasticity of the fluid. Nevertheless, this elastic fluid in the course of several weeks retained all the qualities of true air.

§28

We could here suggest much about air hidden in the pores of bodies and varieties which perhaps are new, but since this belongs rather to the description of unusual actions of this captive air than to showing the reasons for its elasticity, we will leave this for a special treatise.

Supplement to Meditations on the Elasticity of Air

When Lomonosov presented his paper on the elastic force of air to the Academy, his friend and colleague Richmann pointed out that in some respects it was incomplete, especially in its failure to explain Boyle's Law. After considering this, Lomonosov on May 29, 1749, presented his views on this subject to the Academy, and these were printed under the title "Supplementum ad Meditationes de vi aëris elastica" in the same volume as his original paper, *Novi Commentarii Academiae scientiarum imperialis Petropolitanae,* I: 305-312 (1750). The Latin text and Russian translation were printed in *Collected Works,* II (1951), pp. 145-163; and in *Selected Works,* pp. 150-157.

§1

When we read our meditations on the elasticity of air at a session of the Academicians, the illustrious Richmann noted that we passed over a very important property of the elasticity of air, namely, that in our theory we did not include an explanation of why the elasticity of air was proportional to its density. Then I answered that I passed over this, since I had doubts, and I promised to satisfy this position in the future. These doubts as to this law first arose in me because of the disagreement of our theory with this law, and this doubt to a great degree was strengthened by the statements of the illustrious Bernoulli.

§2

Thus, Bernoulli,[1] studying the ejection of balls from cannons, showed that *either elastic air from the puff which is produced by ignited gunpowder is not ordinary air, or that elasticity rises in greater proportion than the density; for the density of air generated by burning gunpowder cannot exceed by more than a thousand times the density of ordinary air,*

1. *Hydrodynamica,* p. 243.

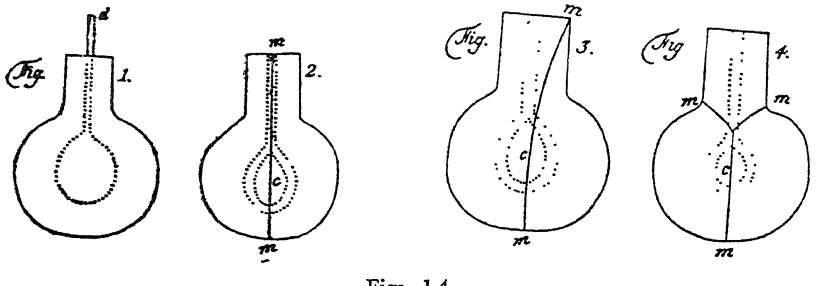
even if the powder were all composed of compressed air which was contained in the powder from the specific weight. He even asserted that the elasticity of this air would have to be still greater if all the powder taken for explosion in the cannon burned in one instant.

§3

That this air is true atmospheric air we have shown in another place.[2] Whether it is to be asserted that the elasticity of air is proportional to its density will be apparent if it becomes possible from other specially carried out experiments to draw conclusions similar to those of Bernoulli himself and to confirm them. For this purpose we have considered most suitable those experiments in which strongly compressed air, acting on the vessel which contains it, breaks it, and from the resistance we can determine the elastic force and compare it to the volume.

§4

As is well known, water going to ice increases in volume and with great force breaks the vessel which contains it; there is no doubt that this is produced by the air liberated from the pores of the water at the moment of freezing, which collects in bubbles. For the study of this we have been busy preparing several hollow glass spheres of different sizes, fitted with thick walled tubes with narrow openings [Figs. 1, 2, 3, 4]; these were



Figs. 1-4

set out filled with water in strong cold which was violent this winter.[3] The part of the water which froze, covering the walls

2. In the Meditations themselves (§ 27) and in a separate dissertation which we have prepared [Dissertation on the Origin and Nature of Niter, § 49].

3. 1749.

of the hollow sphere with a crust of ice, broke several of the spheres, except those whose openings were not fully plugged up by water frozen earlier and in which from the pressure of the internal ice an ice cylinder *d* was pushed out from the opening. Breakage was complete in different directions, but most often along the length of the tube as shown in Figs. 2, 3, 4 by the lines *mm*. After breaking, the residual water ran out and left the hollow *c*.

§5

The largest of the glass cylinders which we used had a diameter of 26 lines of the Paris Royal foot [58.5 mm], the diameter of the cavity was 8 lines, the ice crust had a thickness of about 1½ lines (it was impossible to measure it with the necessary exactness because of the irregularities which were produced, mostly on the inner part of the crust by rapid freezing to the crust itself of residual water flowing out of the cavities; this increased the thickness of the crust; we have taken here the greatest measured thickness). Therefore the diameter of the cavity within the crust was 5 lines. From this, calculation shows that the area of breaking, not counting the tube, was 480 square lines; the area of the great circle which the largest sphere should have formed by the ice crust was 41 square lines. A glass cylinder 25/100 of a Rhenish inch [6.54 mm] in cross section broke at a load of 150 pounds,[4] whence we can calculate that a glass cylinder having a diameter of 1 Paris Royal inch should break at 2572 pounds; and hence a cylinder whose area of breaking was 480 square lines would require for breaking about 10,925 pounds.

§6

If the water in the glass spheres were completely frozen, then the breaking force of the ice would be calculated from the area of the circle made by halving the entire cavity, but since unfrozen water remains in the middle and therefore does not give up its air and does not act on the glass, the acting force should be calculated from the area of the greatest circle of the sphere forming the ice crust, and this area equalled 41 square lines. A column of mercury equal in weight to the aerial one and

4. Muschenbroek in *Notes ad experimenta Academiae del Cimento.*

based on 41 square lines, 28 inches high, weighs 40,242 grains, that is 4 pounds and 3378 grains. Hence, if the water frozen in the crust were completely composed of air, this latter would or should be compressed about 1/2521 parts of the space occupied by it in the atmosphere in order to be in a state to break this sphere. From this, if the density of the air were proportional to the elasticity, then the water itself would be made 2½ times specifically heavier when it was converted to ice, but since this does not occur, then it is clear that our conclusion fully agrees with that of Bernoulli.

§7

I will say frankly that suspicion arises as to the material of the glass, for it could break from sudden cooling and without freezing of the water in the hollow of the sphere. But the experiment was repeated with two other glass spheres filled with water and placed in the frost, always with the same success, while many other similar glass spheres filled or not filled with water placed in the cold simultaneously with the first remained unbroken. The diameter of one sphere was 18 lines, the hollow 5⅔ lines, thickness of the ice crust 1 line; the diameter of the second was 17 lines, hollow 5½ lines, thickness of ice crust ¾ line.

§8

Incidentally, our illustrious colleague Richmann, in the same frost, made experiments on compressing air by the force of cold in a bomb which was broken by the force of freezing water. We measured one bomb; it had a diameter of 94 Paris lines, middle diameter of the hollow was 60 lines, thickness of the ice crust 4 lines, and so the diameter of the water which was not frozen at the moment of breaking was 52 lines. Since this experiment from all points of view fully agrees with those which we made ourselves, it can very well be used for our argument.

§9

We take the strength of the cast iron from which the bomb was made as the average between the strength of iron and glass, since in cast iron glassy particles are mixed with the iron ones. Since it follows from the experiments of Muschenbroek that

the strength of glass is to the strength of iron as 24 to 450, then the average will be 237 so that the force required to break the bomb will be 904105¾ pounds. A cubic inch of mercury weighs 5048 grains; hence a column of mercury having a weight equal to an air column with a cross sectional area equal to the great circle of the ice crust formed in the sphere will be 1,375,159 grains or about 150 pounds. Hence for breaking the bomb, if the whole ice crust were composed of compressed air, the latter should be 6000 times more dense than atmospheric air and the ice crust more than six times heavier than itself.

§10

Water under the bell of an air pump, on removal of the external air, evolves much more air than is driven out by frost from freezing water and collected in bubbles which break the vessel. Hence it is clear that air contained in water does not regain all its elasticity on freezing and thus does not all act on the vessel which contains it. If all the air could act, there would be a much more considerable effect from this itself or the same from a lesser amount of ice. Thus, from these circumstances, perfectly analogous to those described by the illustrious Bernoulli,[5] it also follows that the density of air with great compression is not proportional to its elasticity. Here also is added the finding of Muschenbroek[6] that when air is brought to a volume of less than a quarter it does not further obey the ordinary laws, but shows a greater resistance to the force compressing it. Let us see how this follows from our theory.

§11

Let A and B be two masses of air of equal weight and the interval of vibration between the corpuscles of mass A relate to the interval of vibration of the corpuscles of mass B as a to $a-b$; then the volume of mass B will be related to the volume of mass A as $a^3 : (a-b)^3$. Since therefore the spheres of air vibrate more often, the less the space of vibration, then the frequency of the blows will be inversely proportional to this space. Hence the frequency of the blows between all the spheres of aerial

5. *Hydrody.*, p. 242.
6. *Elem. phys.*, Chap. 36, § 794.

mass A in all three dimensions will be related to the similar frequency of blows between all the spheres of aerial mass B as $(a\text{-}b)^3 : a^3$. But since when mutual blows of the aerial spheres occur more often, their repulsion from each other should be stronger and the elasticity of the air should be greater, then the elasticity of the aerial mass A will be related to the elasticity of aerial mass B as $(a\text{-}b)^3 : a^3$, so that the elasticity of air will be inversely proportional to its volume, or, what is the same thing, proportional to its density.

§12

This would be perfectly true if the aerial spheres B and C, moving back and forth (Fig. 5), rebounding after each blow, would always collide directly with some of the nearest spheres

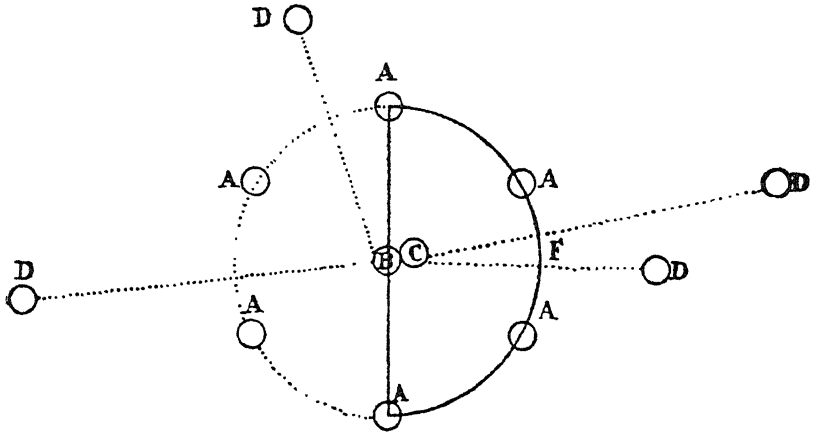


Fig. 5

A and did not frequently fly past through the spaces between them to other encounters with more distant spheres, in which case the blows should occur more rarely and the above relation would be modified. But since it is evident that this hypothesis is impossible, then in fact another reason must intervene. It consists in this and depends upon this: it is possible, we assert, to find variations in vibration by careful study.

§13

No one doubts that aerial corpuscles B and C after colliding more often pass rapidly through the spaces AA untouched by

a corpuscle of *A*, and the diameter of the corpuscles of air have a greater ratio to the spaces of vibration, the more the air is compressed. Further, taking all the vibrations together, infinite in number, we can come to the ratio of the number of vibrations coming from blows on the nearest particles of *A* to the number of vibrations in which the spheres through the spaces *AA* collide in their motion with more distant spheres *D*. This ratio equals the ratio of the number of air particles which can be accommodated between the spheres *A* on the surface of the larger sphere described by the semicircle *AFAB* to the number of spheres *A*, each of which is separated from the other as much as it is from the center *B*. On increasing the density of the air the spheres *A* are closer to each other, lessening the distance between them and showing a less number of vibrations on untouched spheres *A* and therefore the ratio of the number of vibrations in which the spheres pass out through intervals *AA* and strike the more distant spheres *D* to the number of vibrations by which the nearest spheres *A* are struck is lessened. Hence with the greater frequency of blows occurring from the lessened reciprocal distances of the air spheres (§11) is also combined the fact that, due to the lessened size of the space *AA* between the nearest spheres of air, they will more often receive the blows on themselves and by this the resistance of the elasticity of the air is increased above the ratio given in §11. Then on compression of air, when the space of vibration is made less than the diameter of the spheres, all meetings of the spheres will be only with the nearest spheres *A* since they cannot penetrate through the intervals *AA* without striking the sphere *A*. Hence it is evident how the elasticity of air should differ in relation to density when it is most compressed.

On the Relation of the Amount of Material and Weight

In a long letter to Leonhard Euler, written on July 5, 1748 (Latin and Russian texts in *Collected Works,* II (1951), pp. 169-193, and Russian text in *Selected Works,* pp. 122-133), Lomonosov gave a detailed exposition of his views on the relationship of mass to weight. As the letter indicated, he had been led to consider this matter while preparing his essays on the nature of niter and the elasticity of air. Thus his views on this subject belong to the same period as that in which he developed most of his corpuscular ideas. However, he did not publish these views and did not even embody them in a scientific paper. In 1755 the Russian Academy considered offering a prize for the best essay on the subject of the proportionality of the material of a substance to its weight. Although this plan was later withdrawn, Lomonosov was stimulated by the offer to put his ideas in more formal terms. He presented a paper on the subject to the Academy on January 30, 1758. The paper was then deposited in the archives of the Academy and remained undiscovered until 1908. It is evident that Lomonosov did not change his ideas greatly between 1748 and 1758, since much of this paper is a word for word repetition of his letter to Euler. The Latin and Russian texts are given in *Collected Works,* III (1952), pp. 349-371, and the Russian version appears in *Selected Works,* pp. 318-326.

Whenever we consider the great number of different opinions on the phenomena of nature, we cannot see without some sadness of spirit that after such strenuous efforts of notable men, after such glorious discoveries of so many physical phenomena, up to now there is no satisfactory explanation especially of that part of natural science which studies the quality of bodies originating in the most minute parts, unavailable to the visual senses. But this will seem less surprising when we consider that the very first principles of mechanics and of physics itself are still controversial and that most of the famous scholars of our century cannot agree about this. A very clear example is the measure of the force of motion which one in-

dividual takes as a simple, another as a squared relation to the velocity.

Such controversies raise the question of whether there is a relation of the heaviness of a body to the real measure of the amount of its material.

Although many consider this established, and most scholars take as an axiom the proposition: *as is the quantity of a material body, so is its weight,* yet there are many circumstances which speak against this and are so significant that they deserve the attention of the learned world.

Actually this position is without question for homogeneous bodies. But we have never found sufficient evidence that it applies to heterogeneous bodies; and if we take it as true, then it is seen that it is not only insufficient to explain the facts of nature, but in many cases even is an obstacle, as will be clearly shown in what follows.

We express full agreement when we read in Newton that *air of doubled density in a doubled space is quadrupled, in a tripled one sextupled, and we think the same for snow or powder made dense by compression or brought into the liquid state.* But we do not consider it possible to agree unconditionally with the general position expressed thus, that *mass is signified by the weight of each body,* since we cannot make inferences from the particular to the general, and there is no necessity that what is true for homogeneous bodies must also hold for heterogeneous ones. There is no doubt that in one pound of gold the material is half that in two pounds of the same, but there is doubt that for one pound of water and two pounds of gold the same relation applies. Although in another place in Newton there is given proof of the theorem that amounts of material are related to each other as the weights, yet all this proof depends on the hypothesis of Newton that an ethereal fluid either does not exist or is so rarefied that with respect to resistance it can be considered as nothing; thus in the very beginning of the proof he confuses the material of a moving body and its resistance; this however is not the case on a contrary assumption. Actually, assuming a dense ether surrounding all bodies and the least particles of bodies, we can in no way decide and determine exactly how much resistance must be ascribed to the intrinsic material of the moving

body and how much to the resistance of the ether. Finally let us assume that the amount of material is proportional to the weight; we take any sort of body on the surface of the earth whose weight is p, material m. Let this body be carried above the earth to a height, for example, of half its diameter; the weight of the body by the inverse square ratio to the distance from the center of the earth will equal $p : 4$, and the material, on account of the same ratio with the weight will equal $m : 4$, according to the hypothesis; hence we have $m = m : 4$, that is, the whole will be equal to its parts and one and the same thing will not be equal to itself. It is true that the hypothesis admitted by all can be used without danger of error in ordinary mechanics, which is concerned with large bodies, tangible to the senses, and the statement here noted does not destroy the relation of resistance and weight in a reasonably small space. Evidently, however, we cannot introduce this carelessly in explaining the facts which depend on the finest particles of natural bodies. But how the papers of physicists neglect the shapes of the corpuscles so as to satisfy the hypothesis presented above! We can find not a few such assumptions which do not agree with the brilliant simplicity of nature and often contradict one another with reference to the same body.

It is appropriate here to illustrate these doubts by examples. There are bodies, very different in specific gravity which have qualities which cause strong doubts of the truth of the accepted hypothesis. We find such bodies when we compare gold and water. Actually, although water is almost twenty times specifically lighter than gold, yet no external force, however applied, compresses it to lesser volume. Therefore it is very probable that the cohering particles of water material touch each other directly, for penetrating material, if such were found between the touching particles of cohering material, would yield to the least pressure. Hence it follows that the positions of the particles of both bodies are very close. Therefore, in order to save the hypothesis it is necessary to fall back on different sizes or shapes of the corpuscles. Their different sizes can in no way cause differences in density of both bodies if the arrangement and the shapes of the particles are the same in both. For the size of the particles is increased or decreased proportionally and the spaces are empty of the cohering material of the bodies.

Thus, if we wish to assert that the amount of a material body is proportional to its heaviness, it remains only to fall back on different shapes. In order that the density of material in bodies be greatest, the most suitable shape of the corpuscles will be a cube. Thus let us assume that the particles of gold have such a form (although its pores, open to water itself if this is saturated with salts, and also the ductility of this metal prevent ascribing exactly cubic particles to it). But what shape shall we give to the water corpuscles? If we assume they consist of solid spheres (as the majority of physicists consider most probable), then the quantity of material in the gold will be greater by about two fold and not twenty fold. If we assume in each sphere a hollow cavity with a solid shell which is ten times greater, so that the cavity and spherical corpuscle of water will be to the solid cube of gold in density of material about 1 to 20, then the thickness of the shell of the water corpuscle will hardly be more than one sixtieth part of the diameter of its cavity. Under these conditions water will consist of the finest bubbles which can scarcely show resistance to even the weakest pressure, whereas water, pressed by the greatest force, rather penetrates into the narrowest pores of metals than sustains any damage to its volume, and when, at the moment of freezing of water, air collects in small bubbles from its pores by the strong cold and appears with very great elasticity, then the strongest bomb breaks rather than that the water yields any of its space. Actually, evidently, nature best provides for the strength of corpuscles which are designed to resist such forces. And if, as is evident, the hollows of the spherical corpuscles of water material assumed here correspond little with the incompressibility of water, then another type of shape which could be devised in support of the hypothesis which has raised doubts would be still less suitable, since it would also contradict the simplicity, tastelessness, and transparency of water. Thus, if on the basis of the indestructible density and the mobility of water particles we consider with sufficient probability that they are spheres, then we cannot accept as cubic the particles of gold, penetrated by so many pores; if then we assume, as was said, in both bodies the same very close arrangement of particles, we finally have sufficiently weighty reasons for increasingly doubting this hypothesis. In the same way we can discuss many other bodies, for example

the diamond and mercury, in which also the hardness of bodies is connected with the density of their materials. Thus it is very evident that if we assume the correctness of this hypothesis, then the diamond, a body of such amazing hardness, such density and stability that nothing else is known to be a solvent to penetrate its pores and the very strongest fire cannot melt it, consists of material about four times lighter than that which makes up mercury, a liquid permeable to many solvents and volatile. But, perhaps, we have already shown sufficiently the objections to the proposed hypothesis, for it is first of all insufficiently proved, and second is filled with many difficulties. But the examples given are not alone in speaking against it; we find more when we study the reasons for gravity.

No one doubts that phenomena and their consequences become clearer and more understandable when their reasons are known; therefore it is certain that if we understand the reasons for gravity, we will be able to explain differences in specific gravities of bodies. Hence it is necessary, since this is an urgent question, to say what, in general, is the reason for gravity.

However, we will not at this time enter into a quarrel with those who attribute gravity of a body to its actual attributes and therefore do not find it necessary at all to study its causes; but we consider it certain that motion and in general the tendency in a definite direction, as also with gravity, since it is a definite form of motion, can be absent in a body without harm to the existence of the latter; the same can be true for the quantity of motion which arises from the increased rate of fall of a body. Thus, since there should exist a sufficient basis for the fact that a sensible body naturally tends rather to the center of the earth than that it does not so tend, then we must study the cause of gravity. It should arise either from a blow or from mutually attractive forces. That a body moves under the influence of a blow no one doubts; pure attraction remains under question and there are sufficiently convincing reasons which speak against its occurrence in the nature of substances. First of all, if there exists a pure attractive force in a body, then it is necessary to assume that it is innate in it for nothing else than the production of motion; but it is known to everyone that the motion of a body is produced by blows: hence it is shown that for the production of the same result

there are two causes in nature, and that here one contradicts the other. Actually, what could be more contradictory to pure attraction than a simple blow? But no one can deny that the most clearly contradictory causes should produce also the most contradictory results (let no one bring against this as an example the contradiction that animals are killed in the same way by heat and cold, for here I do not imply remote reasons, which can be numerous, but very similar ones which should be unique for each result; thus the most immediate reason for death is stopping the motion of the blood and other fluids of the animal body). Therefore, if pure attraction excites motion in a body, then a blow is the reason for rest, which is false for in fact a blow excites motion; this means that if attraction does not excite motion, then it does not exist at all. Finally, let us assume that in a body pure attractive force exists; then body *A* will attract another body *B*, that is, move it without any sort of blow; this means it is not required that body *A* strike body *B* and so there is no need that it move toward it and since its other movements in which there would be no direction could not have any significance for setting body *B* in motion, then it would follow from this that body *A*, found at full rest, could move body *B* and the latter would move to body *A*. Hence something new would be added to it, just this motion to body *A*, which had not previously existed in it. But all the changes met in nature occur in such a way that if something is added to something, then this is taken away from something else. Thus, as much material is added to some body as is lost to another; as many hours as I spend in sleep, so many I take away from wakefulness, etc. Since this is a general law of nature, it applies also to the laws of motion, and a body which by its blow excites another to motion loses as much of its own motion as it gives to the other body which is moved by it. Thus, by virtue of this law, the addition of motion to body *B* in the direction of body *A* is taken away from where body *B* acquired this motion, that is, from body *A*. But since we cannot take away from any body that which is not in it, then it is necessary that body A is moved when it attracts body *B*. But since it is seen from the above that body *A* is at rest when it attracts body *B*, it is seen to be absurd that the same thing at once is and is not. Thus, since pure attraction cannot exist, therefore gravity should be pro-

duced by a blow, and there should exist a material which pushes a heavy body toward the center of the earth. In a heavy body the finest particles are heavy and have weight, whence it is evident that the gravitational material also acts on the finest particles, freely penetrating into their narrowest pores, and therefore it should be very fluid. In order to show its force with respect to the heavy body it should strike the finest particles, but it can only strike on particles extended and impermeable to it. Hence it follows that a heavy body consists of very minute particles, impenetrable to the gravity material, which acts only on their surfaces. Thus, if body A equals body B in extension and density of material, and the corpuscles of body A on whose surface the gravity material acts are larger than the corpuscles of body B, then body A will be specifically lighter than body B. Actually, let the diameter of one corpuscle of body A equal d, its circumference equal p; then its surface will equal dp. Further, let the diameter of the corpuscle of body B equal $d—e$; its circumference will equal $(d—e)p : d$, its surface $(d—e)^2p : d$. Then let the number of corpuscles of body A equal a. Since body A equals body B in extent and density of materials and the corpuscles of both have the same shape and arrangement (by the hypothesis), then the number of corpuscles of body A will relate to the number of corpuscles of body B as the cube of the diameter of the corpuscles of body B to the cube of the diameter of the corpuscles of body A; that is, as $a : ad^3 / (d—e)^3$, so that the sum of the surfaces of the corpuscles of body A will be to the sum of the surfaces of the corpuscles of body B as $adp\ ad^3 / (d—e)^3 \times (d—e)^2p : d = a/d : a/d : a/d—e$.[1]

Thus the sum of the surfaces of corpuscles of body A is less than the sum of the surfaces of the corpuscles of body B (by the demonstration); therefore the gravity fluid will show more action on body B than on body A. But in both the density of the material is the same (by the hypothesis); hence the amount of material will not be proportional to the weight. This is deduced from the different mass of the corpuscles; the same thing is deduced if we ascribe to the corpuscles of different bodies different shapes also. Thus, if we wish to signify that the weight

1. N.B. Instead of $a/d : a/d–e$, it should be $1 : a/d–e$, or $a : ad/d–e$, or $d–e : d$.

of a body is proportional to the density of its material, then we should either assume that the particles of all bodies impermeable to the gravity fluid in general have one and the same mass and shape, or we should deny this fluid. The first is contradicted by the astonishing differences in the bodies of nature, which urgently requires that the particles of different bodies have different shapes or, in the highest measure, mass; the second contradicts the existence, so very probable, of a gravity material and leads to the defense of occult qualities. Besides this, it is important to consider that if we assume a visible world, full of materials, then we should also assume imponderable materials; otherwise all bodies could not be lifted up or descend by the force of gravity in an ethereal fluid. If we accept imponderable materials, then, passing from the greater to the less, it is necessary to conclude that there exist different materials which yield to other materials in specific gravity, which also follows from the analogy to other qualities which are possessed by sensible bodies. Of course, light can be taken from a body, and so can also be lessened in degree of intensity; the same holds for sound, taste, and many other qualities.

On the basis of these ideas we assume that the specific gravity of a body is changed proportionally to the surface opposing the gravity material which cannot penetrate its corpuscles; in this case not only will all the difficulties mentioned above be removed, but, evidently, there will even be discovered a wide path for the best explanation of very many phenomena and also for the study of the finest corpuscles. Actually we assume that the sum of the surfaces of corpuscles of gold is almost twenty times greater than the sum of the surfaces of water corpuscles in the same volume; it is shown that gold is almost twenty times heavier than water at the same density of material. Here let it not be objected that the pores of gold, due to the fineness of its corpuscles should be so narrow that the corpuscles of water, which due to its lesser weight has a greater size, and even particles of aqua regia could not penetrate them. Experiment shows that aqua regia enters only into those pores of gold which are found between the mixed corpuscles of this metal, which consists of different sorts of principles between which aqua regia cannot penetrate; otherwise the aqua regia

would break up the component parts of gold and hence destroy it completely. Further, by the help of this theory we completely deny the well-known opinion that fire remains fixed in calcined bodies. Actually, though there is no doubt that particles of air continuously flowing over the calcined body mix with the latter and increase its weight, yet if we take into account the experiments made in closed vessels which do not admit of doubt, in which the weight of the calcined body is also increased, then we can answer that due to destruction of the cohesion of the particles by calcination their surfaces, previously covered by mutual contact, freely undergo the action of the gravity fluid; therefore the bodies themselves are more strongly drawn toward the center of the earth. Finally, there occurs the not unimportant basic assumption that if there is a real opinion countering the generally accepted hypothesis, then it will be easier to study the relative sizes of the particles in different bodies on the basis of different weights and cohesions; and hence a great light will be cast on corpuscular philosophy which we can judge in our century to be so neglected, being convinced that the science of the finest particles from which come the particular qualities of sensible bodies is as important in physics as the particles themselves are necessary to create bodies and produce particular qualities.

Meditations on the Solidity and Liquidity of Bodies

Beginning in 1747, Lomonosov carried on a series of experiments on cold, both alone and with his colleagues in the academy. These culminated in the freezing of mercury in a freezing mixture by Academician I. A. Braun on December 14, 1759. Lomonosov was closely associated with Braun in the work, which attracted wide attention throughout Europe, and he subsequently carried on a number of similar experiments himself. This work led him to a series of speculations on the freezing of bodies, and in August 1760 he set these down in a paper, which he presented in Russian to the Academy of Sciences on September 6, 1760. In this he also described some of the actual experiments on freezing mercury. The paper was soon issued in Russian as a separate publication by the Academy, and a Latin translation quickly followed, also as a separate book. The Russian and Latin texts have been published in *Collected Works,* III (1952), pp. 377-409, and the Russian text is in *Selected Works,* pp. 327-341. The Russian text, as written by Lomonosov himself, differs slightly from the Latin version and is a little longer. The following translation is from the Russian text.

§1

Everyone knows how much the solidity and liquidity of bodies depend on differences of heat and cold. Now when the partner in our studies, Professor Braun, has presented a report on his artificial freezing of mercury in the past severe winter and has explained his experiments, I consider it proper to present my own thoughts on the cause for cohesion in various bodies, so that we may more clearly obtain an idea of the freezing and thawing of sensible bodies when they become solid or liquid and thus by describing our work publically, to express our most humble reverence on this festive occasion.

§2

In studying the general reasons for the cohesion of particles, I should first of all appeal to those who have not been inter-

ested in this and have been satisfied with the idea of one attractive force, accepting this without believing in some kind of a blow. Therefore, I assert that no one can fail to acknowledge and accept what I will so firmly demonstrate, which, unless I am deceived, is also new.

§3

If there really were an attractive force, it would have to be innate in a body as a reason for the production of motion. But motion is also produced in a body by striking or repelling, which is clear to everyone. Why should there be two directly opposite reasons, and a quarrel between them, for the production of one action; for what can be more contrary to attraction than repulsion? From directly opposite causes opposite actions should be produced. Here is a feeble argument which apparently seems, for instance, to be urged against this: that animals are killed equally by heat and cold; but these reasons are essentially separate, and there can sometimes be opposition between them, but the immediate and direct cause of death is the suppression of flow and circulation of the blood and other vital fluids. One direct reason was stated by Newton himself, who did not accept attractive forces in his lifetime, but after his death was made their unwilling defender by the overly great zeal of his followers. Thus, if an attracting force produces motion in bodies, then motion cannot be produced by a blow or repulsion. But this is completely false, since repulsion truly produces motion and hence it is not true and undoubted that there is an attractive force in bodies.

§4

If we still concede that there is in bodies a true attractive force, then body A attracts to itself another body B, that is, moves it without any blow, and for this there is no need that A adheres to B and hence it is not necessary that A moves to B; but as another motion of body A in another direction to the motion of body B is not necessary, it follows that A, being entirely without any motion, moves B. Thus B obtains for itself something new, namely, motion toward A which before was not in it. But all changes occurring in nature are of such a state that as much as is taken away from one body, so much is joined

to another; thus, if we decrease some material we add it in another place; as many hours as one devotes to wakefulness, so many hours are taken away from sleep. This general natural law extends in very truth to motion, for a body moving another by its force loses in itself as much as it communicates to another which obtains motion from it. Hence, by this general law the motion transmitted to body *B* is taken away from body *A*. But as nothing can be taken away where nothing is, it is necessary for this that body *A* be in motion when it attracts another body *B* to itself. It follows from the above that body *A* must be without any motion when it attracts another body *B* to itself. And therefore body *A* can be in motion and stand perfectly quiet at the same time. But as this contradicts itself and opposes the general philosophical statement that *one and the same substance at one time can and cannot be,* for the sake of truth and certainty an attractive force cannot occur in nature.

§5

Thus it follows that the particles of which sensible bodies consist, due to a blow, or more properly speaking, due to compression, force out by their mutual cohering contact some fluid which surrounds their material. Therefore it is necessary to consider how this fluid material is squeezed out in the cohering of particles which compose the body and thus briefly to explain the properties of solids and liquids.

§6

Does not someone here ask that I show what is the material or how the cohesion of its particles compresses the corpuscles of the liquid which surrounds them? Would not he say that I am now obliged to recognize the existence of attractive forces? By no means. Everyone who knows the difference between the requirements for the essential attributes of bodies and for changes in their qualities will be able to see clearly that the reasons for these cannot be demonstrated nor should we ask what must be in substances for their existence: for example, why a triangle has three sides, why a body has extension, and similar questions. Thus the cause of cohesion should be sought where we see that insensible particles cohere or are free from cohering bonds or increase or decrease the force of their co-

herence. Then we can ask why this is so, and in no other way. Nor do we recognize changes in the union of the insensible particles which compose bodies, and the reasons for this also should not be asked. A philosophical *principle,* called a *satisfactory reason,* does not extend to the essential attributes of a body. From such incorrect usage comes the discussion, so unreal in the light of scholarship, of simple substances, that is, of particles which do not have any extension. If extension is an essential attribute of a body, without which this body cannot exist, and almost all the virtue of the body consists in extension, then questions and quarrels concerning the nonextensive particles of an extensive body are futile; as the best method in such a case we should seek proof of the definition instead of finding a proof drawn from the definition.

§7

Considering the planes of contact of the particles, I see at once many with different numbers of shapes, which many physicists unsuccessfully ascribe to insensible particles. Yet their purpose is praiseworthy, for it is as necessary to study the principles of bodies as to have the principles themselves. Since a body cannot exist without insensible particles, the deepest study of physics by scholars is impossible without them. In an hour we can see only the surface, but with time we can know how and by what forces they are moved, separated into equal and different parts. Physicists and especially chemists would be in the dark if they did not know the structure of the internal insensible parts. Therefore I do not allow myself to be counted among the hopeless ones who are called careful physicists but are not pleased at the knowledge of the shapes of insensible particles. I am not repelled from studying particles which escape the view because of their smallness, unavailable to physical apparatus because of imaginary shapes of the particles: wedges, needles, hooks, rings, bubbles, and many others chosen without any basis, for in twenty years of frequent discussions of this and from related experiments I have seen that nature, satisfied with sphericity only, eases the task of studying her secrets.

§8

But one thing has displeased me, though in fact it is very probable: I was displeased that some intelligent people, most

notable heroes of the learned world, considered the material of particles spherical, especially liquids (and all solid bodies turned into liquids by the force of fire); I was not satisfied with the reasoning by analogy that all natural bodies tended to be spheres and preferred this form from the greatest even to the smallest, from the chief bodies of this world, as our earth, to the finest and simplest spheres invisible to the eye, which make up blood. Disregarding the fact that in the parts of animals and plants, seeds and fruits have largely a circular form, that the more finely divided all liquid materials are, the more circular they become, not taking into the discussion the evidence from the unnumbered multitude of spherical raindrops, I will rest my argument on rigorous mathematics.

§9

I have shown before this[1] that Aristotelian elementary fire, or, according to the new scholarly name, special calorific material, transferred and wandering from body to body, travels without the least probable cause and is only a fiction: and I assert that fire and heat consist of a rotary motion of particles, especially of the material which makes up coherent bodies. I have defended my system from unfounded objections, and false contradictions have been presented in vain. And above all, new results are immovably confirmed.[2] And for this reason without hesitation we use this as the basis for proof of the sphericity of the insensible particles which compose bodies.

§10

Thus, when the insensible particles of warm bodies are transformed into rotary motion, let us assume that the particles of warm bodies are not spheres, but some other sort of shape, for example, cubic; from this would result the fact that they, rotating, are in contact at times with angles. From this it should follow: 1) that the cohesion of particles which are solid bodies is momentarily changed, for on contact by angles little or nothing can hold one to the other; 2) all the diagonals and all the lines which form angles to the side of the corpuscles would necessarily be longer, so that from moment to moment there

1. Meditations on the Cause of Heat and Cold, *Nov. Comm.*, Vol. 1.
2. In Oration on the Origin of Light and Color.

should be a change of length in sensible bodies and there would be a continuous vibration which would be stronger, the warmer the body. But as from the evidence of our senses neither of these effects is found in bodies, there are no angular shapes or any other which has unequal diameters in warm bodies; that is, all shapes are impossible except the spherical.

§11

All sensible bodies of any shape, put on a balance in equilibrium with weights in all positions, remain without fail in equilibrium; for example, marble or metallic pyramids placed on their bottom or on their ends, on their sides or on the angles, never show either increase or decrease in heaviness. These experiments, though very simple and known to everyon, yet are very important in the present case. We neglect and slide past many such simple and everyday effects which in the study of nature point the way to great discoveries, and we undertake difficult experiments, forgetting the very famous statement that is simple and based on irrefutable mathematics, that *every substance equals its own size,* on which almost all mathematics is founded. From the above mentioned everyday and very simple art, it follows that all particles composing a body are in essence spherical shapes. For the action of gravitational material always and in the same way affects the impenetrable surfaces of the corpuscles in any position of these bodies and if shapes of the particles were not spherical, then all positions of the surface should differ for the gravitational material, with different forces and different weights. Thus the particles composing bodies through which gravitational material cannot pass and only strikes the surface should be spherical.

§12

Having shown the spherical nature of the particles composing sensible bodies, where can we find contact surfaces? For spheres do not touch one another except at one point. To answer this question satisfactorily it is necessary for me to give a definition of the surface of contact (which should better be called the surface of cohesion), namely, that it is a circle whose diameter is the line *BID* (Fig. 1) between the particles *A* and *C* which are in contact, whose periphery is occupied by the very small

spheres B and D of compressed liquid material, not reaching to I because of the narrow spaces EFI and GHI. Assuming this, there will be no compressed material on the cross sections EIG and FIH of the spheres A and C, since there is no room. Thus, particles A and C, exposed to the compressed fluid on the rest of the surface, cohere by the measure of the circle or plane of coherence.

§13

Hence the following rule results: *the larger the insensible particles composing a body, the stronger is the union, and the smaller they are, the weaker it is.* When cohering particles are spheres, then let the radii of the larger particles (Fig. 1) AB, CF, AI, $CI = a$, the radii EB and BF of the particles of compressed material $= r$. Then by construction of the figure it is seen that BI is perpendicular to AC; hence BI will be $\sqrt{[(a+r)^2 - a^2]}$. But as AD, DC, AB, BC are equal to each other, triangle ADC will $=$ and $\sim ABC$; whence $BI = DI$; therefore $BD = 2\sqrt{[(a+r)^2 - a^2]}$ = the diameter of the plane of cohesion of particles A and C. Then let p be the periphery of the circle whose diameter $= 1$; then the plane of cohesion itself will $= p\sqrt{[(a+r)^2 - a^2]}$. Finally, let the radii of the lesser particles composing bodies A and $C = a - e$ and the radii of the particles of compressed material $= r$. Since the rest will happen as shown above, then $BD = 2\sqrt{[(a-e+r)^2 - (a-e)^2]}$ = the diameter of the planes of cohesion of the lesser particles, and the plane of cohesion itself $= p\,[(a-e+r)^2 - (a-e)^2]$. Thus the plane of cohesion of the larger particles will be to the plane of cohesion of the smaller particles as $p\,[(a+r)^2 - a^2]$ to $p\,[(a-e+r)^2 - (a-e)^2] = (a+r)^2 - a^2$ to $(a-e+r)^2 - (a-e)^2 = r + 2a$ to $r + 2(a-e)$. By this the plane of cohesion of the greater particles will be larger than the plane of cohesion of the lesser particles; hence the larger the particles, the more strongly they cohere; the smaller they are, the more weakly they cohere.

§14

Thus it is not difficult to conclude from this that if many and varied properties are caused by the cohesion of particles,

then by this rule they can be explained by the different sizes of the particles in a mixed body. For this reason let the students of nature cease to marvel and doubt that all special qualities of bodies can come from particles which have a spherical shape only, and especially take into consideration the force of *cohesion* of particles shown in the oration on the origin of light and colors. Beyond this, we take as an example an art by which from round threads, especially if they have different thicknesses, numberless and varied multitudes of tissues and networks of substances are produced in excellent designs by varying their positions.

§15

It has already been shown clearly enough how various sizes of particles act in producing liquid and solid bodies. Therefore it remains to consider how the forces of heat and cold act externally, for differences in size are properties of the particles themselves.

§16

From the system of rotary calorific motion it appears that the particles of warm bodies spin faster and with greater force and repel each other;[3] therefore the cohesion of these particles should become weaker, the greater the warmth or heat in the body itself, and so it may be said that they are not only converted into a liquid, but, losing all interspecific cohesion between the particles, and their very contact, they are dispersed into a vapor.

§17

Therefore much less heat motion is required for obtaining and keeping bodies liquid if their particles are smaller than for those which are larger, and it is not surprising that mercury, the fineness and thinness of whose particles have been indicated by many chemical and medical experiments, keeps its liquidity at very low heats which we by our senses call severe cold and strong frost. For, according to the system of calorific motion, all bodies have heat as long as the particles are moved by rotary motion, although they may seem very cold.

3. See Meditations on the Cause of Heat and Cold, § 23.

§18

In spite of this, bodies of the same nature as mercury, that is, metals, have a stronger cohesion between their particles, and the larger they are than mercury, the greater is the fire required to melt them. The greater size of the particles making up metals is clear from this, that mercury enters their pores.

§19

But there are infinitely many properties and qualities which occur in solid and liquid bodies from different cohesions of their particles, as different degrees of viscosity, brittleness, softness, friability, ductility, elasticity, and others which require varied and prolonged consideration and clear understanding by the keenest physicists; therefore, leaving these for the future, we will discuss only how sensible bodies can be compressed or expanded from boiling to freezing, and in very fact, are compressed and expanded.

§20

First we consider speculations on the different positions which the particles can occupy because of the spherical shape which was established with certainty above. Four spherical particles in close contact and a state of cohesion can be inscribed in an equilateral rhombic figure, and in a spacial position and in contact, this should have the form of a cube. Such equilateral figures *ABCD* (Fig. 2) and *ABCD* (Fig. 3) have the proportion to each other as AB^3 *to* $\frac{1}{2}\sqrt{(AB^2 + BC^2} \times AB^2$, that is, as AB^3 is to $AB^3\sqrt{\frac{1}{2}} = 1 : \sqrt{\frac{1}{2}} = 1000$ to $\sqrt{500000}$ because $AC = BC$. For such a rhombic body can be divided into two equal prisms *ADCFBE* and *ADCFGH* having a common square side *ADCF* (Fig. 4). And since the angles *ABC* and *FBD* are right angles, then the half diagonal *AC* equals the altitude *BK* of the prism *ACDFBE* or half of all the rhombic body. That is, the cubic body to the rhombic body will be almost as 1000 to 707.

§21

Hence it follows: 1) as far as these are simple bodies, that is, composed of the same particles and without foreign materials

in the pores, they can be expanded and compressed without destroying the cohesion, although they can increase and decrease; 2) when particles of foreign material, for example, air, are found between them in the pores, the particles cannot attain to intimate rhombic cohesion and hence cannot always attain to such a great crowding as shown above in §20; however, they still have sufficient room for compression and expansion, and with different amounts of foreign material there can be differences in compression and expansion; 3) in the cubic form there should be twelve contacts between the eight particles, and in the rhombic, eighteen, from which it is not surprising that the particles placed in the rhombic form acquire hardness from it, losing liquidity more strongly when six more contacts are established.

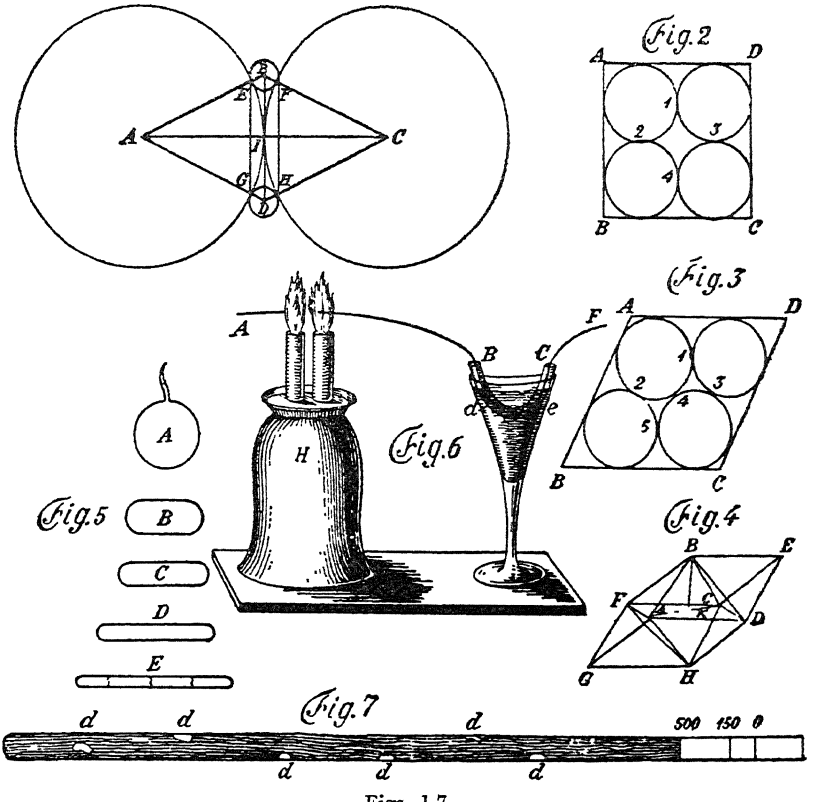
§22

Different bodies show different compressions in experiments. In all those which it is possible to measure, it is not difficult to carry out freezing and boiling, as in water, in oils, and in solutions of different salts. In those bodies in which freezing has not yet been found it is impossible to establish the limits of attraction. This happened with mercury, for until the last winter it had not been frozen and no one hoped for this. But now it remains only to check by discussion and experiment the disagreements between the observations at what degree below boiling mercury should freeze. As this can be seen from my experiments, I add these here.

§23

December 26, 1759, when the frost was 208 degrees, I put a thermometer in the snow into which I had poured aqua fortis; the snow then melted like an oil, as happens close to its melting; the mercury in the thermometer dropped to 330 degrees, then, still applying new snow, we added spirit of salt; the mercury sank to 495 degrees; still adding acid, we saw the mercury at 534 degrees. On removing the thermometer for a short time from the mixture, the mercury reached 552 degrees. Finally as we added to newly applied snow the so-called oil of vitriol, in an instant the snow was converted into an almost liquid ma-

terial and the mercury sank to 1260 degrees.[4] Thus, not doubting that it was already frozen, I quickly struck the sphere with a copper compass and the glass shell was shattered and fell



Figs. 1-7

4. [This work has been analyzed by V. Ya. Bialyk in *Lomonosov, Sbornik Statei i Materialov,* III (Academy of Sciences Press, Moscow and Leningrad, 1951), pp. 52-65. He points out that Lomonosov was here using the Delisle thermometer, in which the boiling point of water is 0°, the melting point of ice is 150°. Thus the initial temperature of the experiment, 208° Delisle, was about −38° C, and this is the temperature which Lomonosov recorded for the melting point of mercury. The correct value is −38.87°. The much lower values recorded as more freezing mixture was added are due to the fact that the mercury in the bulb of the thermometer began to freeze on the walls of the bulb, leaving a core of unfrozen mercury in the middle, in contact with the still unfrozen mercury in the stem of the thermometer. As mercury freezes, it undergoes a strong contraction in volume. Thus with progressive freezing of the central core, the mercury in the stem was drawn further down, giving the lower values recorded. In §24 Lomonosov notes that when the mercury in the stem froze, open spaces were left below it as the liquid in the bulb continued to freeze.]

away from the mercury ball which remained with a tail reaching into the tube of the thermometer like a pure silver wire which bent freely like a soft metal, and had the thickness of ¼ of a line. After this, striking the ball of mercury with a butt, I felt that it had a hardness like tin or lead. From the first blow to the fourth it was compressed without a flaw, and from the fifth, sixth and seventh blows it showed cracks (Fig. 5). *A* shows the ball of mercury with the tail, *B* after the first blow, *C* after the second, *D* after the third and fourth, *E* after the fifth, sixth, and seventh. The mercury was changed by hammering and cutting with a knife, and after about 20 minutes it began to pass into an amalgam or into a paste and quickly regained its lost liquidity, that is, melted at such a great frost as 208 degrees. Inside there was no liquid, nor were pores noted, and the solidity was greater than in later experiments. And though, because of haste, I did not observe whether there was any crack in the glass sphere, yet there would be no danger in this that the mercury would flow out, for the mercury itself already had created a wall when at the first fall in temperature its surface became a solid body and served instead of the vessel to contain that part which had not yet frozen inside.

§24

According to the experiments made in later frosts I found: 1) that mercury at about 130 degrees begins to thicken somewhat. This can be seen clearly in a narrow bent glass tube, since the mercury itself does not reach equilibrium as fast as at the ordinary warmth; 2) at about 500 degrees it stops up the tube, but in the middle of the globe it is for the most part unfrozen or is filled with very many obvious pores; 3) in a long, narrow glass cylinder or tube I have sometimes seen frozen mercury with obvious gaps (Fig. 7); 4) when the tube is warmed by hand, the mercury sometimes shrinks further; 5) we should note here, although it does not exactly relate to this subject, that the electrical force acts through frozen mercury and through glowing iron. The method of the experiment is shown in Fig. 6. *BdeC* is the bent tube containing the mercury immersed in a freezing material, *d* the end of the wire, *AB*, dipping into the mercury and extending from an electrical indicator and heated by candles put on the bottom of glass vessel *H*;

e is the end of the wire *CF* at the other end of the tube, dipping into the mercury and extending from an electrical globe.

§25

From all these experiments and in agreement with the ideas (§20) we see that: 1) differences in the limits of freezing of mercury in the thermometer occur due to unequal rate of freezing in the thin thermometer tube. For it is natural that small amounts of mercury should freeze faster than much larger amounts in the bulb. And thus the freezing mercury in the tube blocks the way and entirely plugs it up while in the globe freezing has occurred only on the surface and the middle is entirely liquid and therefore the thermometer does not show a lower limit of freezing, but remains at the same degree at which mercury froze in the tube; 2) the limit of freezing of mercury should be about 1300 degrees and since the material frozen in the cylindrical tube contains breaks and empty spaces within itself (Fig. 7) while it sank only to 500 degrees, according to my calculations mercury should contract further to 1000 degrees if all its empty spaces were filled; moreover, if mercury when first frozen was without sensible cavities all through the frozen solid, it would sink this low; 3) bodies in positions in space closest to each other have a measure of extension between them as 1000 to 707 (§20), and mercury from its boiling to its freezing by my observations is compressed by 1647, that is, above 0 to 414 and below to 1260 degrees of the thermometer. Hence the size decreases about 16/100; according to the theory there can still be no little further compression to 3000 degrees. However, this compression may occur to some extent after freezing of the mercury.

§26

There are still not a few liquid bodies which have not become solid in the strongest frost and their nature is not changed into ice; these, nevertheless, like mercury, require detailed study. In times to come we will not let the chance to study these diligently pass, any more than other studies of the riches of nature according to the duties assigned by Peter the Great to our institution. Divine Providence, advancing the welfare of Russia and the fortunes of our all gracious Autocrat for her

deathless glory will not deprive us of the advance and increase in the progress of science here, and by the use of our native wisdom, for our institutions which are charged with the general good. Rooted and strengthened in the zeal and powerful genius of the sons of Russia for the higher sciences under the generous patronage of the great Elizabeth, we will brilliantly express the forms, examples, and encouragement of our true advantages and endless favors, for the supremacy of the scholars of our country in all future generations.

Oration on the Origin of Light. A New Theory of Color, Presented in a Public Meeting of the Imperial Academy of Sciences, July 1, 1756, by Mikhail Lomonosov

Lomonosov was interested in the subject of optics from the beginning of his career, and when he turned to the manufacture of mosaics, he extended this interest to the phenomenon of color. After he began his experiments on the preparation of colored glasses in the chemical laboratory built for him in 1748, he worked intensively in this field. Between 1750 and 1754, as indicated in letters to Euler, he developed a theory of color along with his practical work. The application of his corpuscular theory was extended from the kinetics of material bodies to the kinetics of the matter of ether, and he combined his chemical and physical views to produce a form of wave theory of light and color. This is one of the few extensions of his theoretical ideas which he carried out after he ceased to work very actively in theoretical physics and chemistry in about 1750. In 1756 he felt ready to present his views to the Academy, and after several preliminary discussions, he gave his formal oration on July 1, 1756. It was published by the Academy as a separate issue of 400 copies in Russian in 1758; a Latin translation, also in 400 copies, was issued in 1759. The work was widely known and commented upon by scholars in western Europe at the time, and was known also to Thomas Young when he worked on the theory of color. The Russian text is given in *Collected Works,* III (1952), pp. 315-344, and in *Selected Works,* pp. 294-317.

The investigation of nature is difficult, my auditors, but it is pleasant, useful, and holy. The more its secrets reach the mind, the greater is the pleasure felt by the heart. The more our zeal thus expands, the more abundantly do we gather its fruits for the use of the world. The more deeply the discussion

of such marvelous matters penetrates to the reasons themselves, the more clearly do we see the impenetrability of the everliving Creator. In His omnipotence, majesty, and great wisdom, we find the first, general, true and outspoken teachings of the visible world. The heavens announce the glory of God. He gives first place to the sun, that is, in it we see the divine radiance more clearly than in any other object. Because of the vastness of its universal structure it shines continuously to the farthest planets, exceeding the dreams of human swiftness by its instantaneous and incomprehensible rays. By their continuous and lightning-like rapidity these swift and favoring rays arouse other creatures to industry, shedding light, warming, and animating not only the human mind, but also, it seems, the dumb beasts who are animated by some divine presence. What is this measureless light which seems to be an ocean in which the internal sanctuary of nature is revealed to the curious eye and by whose rays a great part of the other secrets of nature are revealed to the zealous seeker?

Many treatises in different countries, appearing in different centuries, explain this. Untiring investigators have overcome many hindrances and have eased the work of those who followed them; they have driven away the dark clouds and have penetrated further into pure heaven. But just as the sensitive eye cannot look directly at the sun, so also the vision of reasoning grows weak in studying the causes of the origin of light and its separation into different colors. What is left to hope for? To cease the work? To give way to despair of success? Never! Perhaps such is the wish of negligent persons, unworthy of the heroes who have made such great progress in studying nature. We see how they have collected a great mass of material on this subject or how, as is said of the ancient giants, they have drawn near to the source of such radiance, such magnificence of color. We ascend to the heights after them without fear, we advance on their strong shoulders, and rising above all the darkness of hindering ideas, as much as possible we turn our keen and discerning eyes to the study of the causes for the origin of light and its separation into different colors.

At the beginning of this undertaking, let us analyze the basis for this mighty thing, established by so many creative minds with consistent or conflicting views, and where the theories

are not organized or are uncertain, we will try to correct and strengthen them by the possibilities which occur to us. Finally we will begin to combine the systems.

Colors are produced from light; therefore we should first consider its causes, nature, and properties in general; then study its origin. Passing over the occult qualities of the ancients, I will begin with the opinions of the present day, illuminated as they are by the brightest physical knowledge. There are two main paths here: the first is the Cartesian, confirmed and explained by Huygens; the second, originated by Gassendi, was accepted and its significance further explained by Newton. The difference between these two opinions is a difference in motion. Both consider an exceedingly subtle fluid, hence an intangible substance. But the motion according to Newton is assumed to be flowing from the light source like a river spreading in all directions; according to Descartes it is a continuous oscillation without flowing. We will consider with attention and care which of these opinions is true and sufficient to explain the properties of light and color.

For a clear and detailed understanding we should discuss all sorts of possible motion in general. Thus, assuming a very subtle and intangible fluid as the material of light, which no one now doubts, we find three possible motions for this, and which actually is or is not possible we will show later. The first motion can be flowing or passing along, as Gassendi and Newton think, by which the ether (the material of light as it was called by the ancients and by many at the present time) moves from the sun and other large or small sources in all directions like a spreading river. The second motion can be a vibration in the ether, according to the opinion of Descartes and Huygens, by which it acts like very small and frequent waves in all directions from the sun, spreading them through the universal ocean of matter like quiet water in which parallel circular waves spread in all directions from a falling stone without any flowing motion. The third motion can be rotary, when each intangible particle making up the ether rotates around its center or axis. Whether these three possible motions of the ether actually produce light and color must be studied in order and attentively.

The opinion that the cause of light is a flowing motion of the

ether is purely arbitrary and has no basis in evidence. Only two circumstances show some sort of probability: the first is the law of light refraction discovered by Newton, the second is the sensible time required for the light from the sun to reach us. But the law is based on a similar arbitrary assumption of the force of attraction of bodies whose validity is now denied by the most learned physicists as an occult quality from the old Aristotelian school which reconverts healthy people to madness. Therefore, although it has been supported by intelligent authors, this does not confirm the theory. The sensible, though very short time in which light from the sun reaches the earth no more confirms the flowing motion of the ether than does the duration of time in spreading the voice after a call over a known distance show the flowing of air. If anyone says that light from the sun occurs by the flowing of ether like a river because there is a sensible time before the light from the sun reaches our sight, then he should conclude that there is a like consequence that air flows from a sounding dulcimer in all directions with the same speed that a voice reaches the ear. But I think of the speed of a strong wind when air in one second is blown 60 feet, raising great waves in the water and tearing up trees by their roots, and I reason that if the air moves as fast in flowing from the strings as does the voice, this is more than a thousand feet a second, and by such music mountains would be torn from their places.

And though neither conjecture mentioned as being useful in establishing this opinion can well serve as a probable proof, yet we concede the time and, assuming that light from the sun spreads in all directions by flow of ether, we shall see what follows.

It has been shown sufficiently by the laws of mechanics, confirmed by daily experience and everything generally accepted, that the smaller and lighter a body is, the less it opposes a motive force and the less momentum it acquires; and also, the more it encounters resistance, the more rapidly is its course changed. For example, if anyone casts a small grain of sand from a sling, does it fly as fast and as far as a rock similarly thrown by a human hand? What can be finer and lighter than a single particle making up the ether? And how enormous is the distance from us to the sun? And who can dream of a faster

flow than the ether, according to the opinion cited above? And what stronger drag can there be than the attraction to the sun which draws to it not only our earth, but other greater bodies, pulling them out of straight line motion? Can we think of the origin of light by a flowing motion of the ether when there are such difficulties?

Let us place a small, black and nontransparent grain of sand in the brilliant sunlight for twelve hours. During this whole time there flows to it continuously the light from the entire visible semicircle of the sun which is included in the conical expanse which has the circle of the sun at the bottom and the grain of sand at the apex. The cubic content of this conical space contains by calculation about seven hundred and twenty million cubic radii of the earth. In every eight minutes the spread of light from the sun to the earth is completed, and so in twelve hours there pass from it to this grain of sand eight thousand six hundred and forty million cubic earth radii of ether material. Let us remove the grain of sand from the sunlight and place it in a small, dark, cold room; the heat acquired from the sun disappears at once and not the least light remains. Even if this experiment were repeated for a whole year or were carried on for a century, the black grain of sand would always remain black and in the dark would not give off any light. A black material does not reflect the light which reaches it nor does this light penetrate through it. Tell me, friends and defenders of the opinion of the flowing motion of the material which produces light, in this case where is it hiding? You can only say that it is collected in the grain of sand and remains there completely. But is it possible for it to fit into such a quantity of material? I know that you divide the material of light into such fine particles and place them in universal space with so little density that the whole quantity can be compressed and packed in the porous crevices of one grain of sand. Although there is no basis or evidence for this separation of yours, yet I will grant you such conditions, provided that according to your rules I will be allowed to divide the material into equally fine particles. You cannot deny me this. Thus, I divide the surface of the black and nontransparent grain of sand into many millions of parts, of which each is illuminated by the whole visible semicircle of the sun; to

each of them runs the awesome amount of ether material which, when put into them, remains there. Where do you find such a place? Perhaps you can divide the matter still more minutely. But in the same way I will have the right to divide the particles on the surface of the grain of sand and each will use as much light. See how your opinion is burdened with difficulties.

But you still say that while it is true that we see difficulties we do not see impossibilities, which alone could produce contradictory conclusions from the theory. I reply: difficulties are often very close to impossibilities, and these I happen to find in more than one way in your theory.

Among known substances what is harder than the diamond? What is more transparent? Hardness requires sufficient material and narrow pores; transparency can scarcely be allowed to the constituent matter of the diamond if we assume that light extends by a flowing motion of the ether material. For from each point of the diamond's surface and of all the interior of its body to each point on the whole surface and in all the interior of its body light passes in a straight line. Hence in all these directions straight line pores extend into the whole diamond. Assuming this, the diamond not only should consist of rarefied and friable material, but should everywhere be empty within. It follows from the hardness that the constituents of its particles cohere closely; from the transparency we conclude not only a friable nature, but almost emptiness surrounded by a fragile shell. Because these results contradict each other we must assume that the theory that light from the sun extends itself by a flowing motion of the ether is incorrect.

Let us still assume that light extends from the sun and other lighted bodies by a flowing motion of the ether. New impossibilities, new contradictions arise. In the diamond, transparent on all sides, from each point of its surface and in all the interior of the body extend the straight line pores of the whole diamond; but these pores carry the material of light, as shown above. Light is transmitted from one side to the other without hindrance by an equal force. Let us place the diamond between two candles. The light from both sides passes through the diamond with equal force, and one candle can be seen from one side through the diamond at the same time as the other from the other side. What is this? Have we abolished mechan-

ics? Do we assume that when two fluid materials meet in equal amounts and with equal force from either side in a narrow pore such as must exist in the diamond they do not encounter and stop each other?

How much more is there? When the light of many thousands of burning candles passes through the pores of a diamond set between them, how many crossings and meetings of the flowing material of light must there be at innumerable angles of inclination; but there is no hindrance and not the least confusion. What is the proper logical conclusion? Where are the indestructible laws of motion?

These disproofs would be sufficient, but in order to eliminate the last trace of the idea, I suggest the following.

Is it possible in nature that one and the same substance is larger than itself? The immutable laws of mathematics affirm that one and the same substance is always equal to itself in size. A denial of this is wrong and contradicts the daily experience and reasoning of sane men. But all this follows from the position and opinions of Gassendi and Newton. Rays of the sun are reflected from within the walls of a glass prism so strongly that an object in a given position is observed as clearly as if this object were seen directly. It follows from this that all the rays are reflected back from the side mentioned and very few of them pass through. The viewed object can be seen as clearly from the other side through the same wall as if it were in direct sight. From this it follows without dispute that all the rays of the sun pass through this side and very few of them are reflected. Is not this what follows from the theory mentioned? As many rays are reflected from this surface as fall on it, and as many pass through it, that is, the material of the sun's rays will be doubled. Now we must hold and assert one of the two ideas, either the theory that the spread of ether material occurs by a flowing motion is false or it is true, and therefore we believe that one and the same substance at the same time is greater than itself.

Now that we have considered the impossibility of this motion of the ether material, we turn to the second theory, that is, we ask whether oscillatory motion can be the cause of light.

I have shown in my meditation on the cause of heat and cold that heat comes from rotary motion of the particles which

compose the body itself. But although many former objections have been clearly shown to be incorrect, yet we should not fail to confirm this again by new conclusions drawn from the art itself.

When iron is struck, it is heated; its own material is compressed more densely and foreign matter is forced out; this shows clearly that the foreign material is not cooled when made smaller and the essential matter which is compressed is warmed by friction and rotation of the particles.

When copper and other metals are heated in aqua fortis or lime is moistened with water, then without any external warming of these bodies, heat is produced spontaneously in them. According to the opinion of the defenders of a caloric material, this should be collected from another neighboring body, and hence this other body should grow cold. But this is contrary to all experience. For an arbitrarily assumed heat material exists in equilibrium and does not create itself; it maintains an equilibrium when it passes from a hot body to a cold one, heating the latter and cooling the first by an equal degree of heat; it does not maintain an equilibrium when the lime is heated without cooling of a substance lying near it; a clear contradiction.

No matter how long lead is kept in boiling water, it will not acquire more heat than we find in the boiling water itself by the thermometer. In the opinion of the believers in heat material, this enters the insensible pores and fills them in accord with their size. The same lead outside of water acquires for itself an incomparably greater amount of heat; it melts, begins to burn, and is changed into a glass. Here, according to the idea of departure and entrance of heat matter, it should follow that the same lead outside of water has larger pores than when in water and in itself is at the same time unequal and dissimilar, though it remains lead.

Boiling water extinguishes incandescent iron. Hence, in the opinion of those who assume the cause of heat and cold to be a material of fire passing from one body to another, this material passes from the iron into the boiling water. But according to well-known experiments and indisputable conclusions, it is clear that when water boils it cannot become hotter. Hence, according to the same opinion it cannot take any more

heat material at all into itself. You see, a clear contradiction. At one and the same time water accepts and does not accept heat material from the same iron.

Heat is continually given off from animals and warms objects near them. Many of them never accept hot food. You champions and defenders of heat material, explain to me by what path heat enters animals insensibly and leaves sensibly. Perhaps when it enters it causes cold? That is, cold heat, just like dark light, moist dryness, soft hardness, a rectangular circle.

All these difficulties, or to speak more correctly, impossibilities, disappear when we assume that heat consists of a rotary motion of the insensible particles which make up bodies. It is not necessary for some strange, incomprehensible heat material to pass from body to body, a fact which not only is confirmed by experiment, but can also be explained clearly. The rotary motion of particles is sufficient to explain and demonstrate all the properties of heat. For further verification of this I refer the seeker to my Meditations on the Cause of Heat and Cold and to my answer to the critics of these meditations.

Now it is time to consider whether rotary motion of the ether particles can be the cause of light.

Although the sun illuminates and warms at the same time, yet there are many cases when there is not the least light with a great heat and when along with a bright light we find no heat. Iron taken from the forge while still hot does not glow in the dark but retains so much heat in itself that it forces water to boil, chars wood, and melts lead and tin. On the other hand, the sun's rays reflected from a full moon and collected by a burning glass give a very clear and bright light but do not produce sensible heat. I will not mention the electric spark, phosphors and other materials which produce light in the dark without heat. For when there is fire without light and light without fire, then these must each originate from a different cause. Light and heat are gathered by earthly bodies from the sun through the ether. Therefore we must conclude that both are produced by the same material, but by different motions. The flowing motion has been shown to be impossible; rotary motion is the cause of fire and heat. Therefore when the ether

produces heat in earthly bodies, that is, produces rotary motion of the particles, it can have another motion. Since ether cannot have a flowing motion and the rotary motion is the cause of heat without light, there remains only the third, an oscillating motion of the ether which should be the cause of light.

Although this has already been sufficiently shown, yet we can still consider whether in the spreading of light an oscillatory motion contradicts the consequences which were drawn from the idea of the flowing motion of ether, and second, whether it can explain the different properties of light.

As to the first, we have a clear example in the oscillatory motion of the air which spreads voices from place to place. Just as there are different voices which are all heard satisfactorily, so we can hear various musical tones differing in loudness from different instruments, and also the voices of birds and other animals; also thunder, ringing sounds, knocks, crackling, whistles, screams, creaks, murmurs, and their different directions and positions, and besides these, the different sounds of the letters in different languages. All these innumerable different voices come in straight lines, intersecting each other not only at all possible angles, but also meeting directly, and one does not nullify another. Standing near a sounding dulcimer, I hear on one side the singing of a nightingale and on the other the song and voice of the singer; there the sound of bells, somewhere else the trampling of horses: all these voices come to my ears and many others; whichever one of them I pay most attention to, that one I hear more clearly. Thus we have proof that in a variety of cases nature uses an oscillatory motion of fluid bodies, just as in air. Since we showed above the impossibility of a flowing motion of the ether, then we certainly should accept its oscillatory motion as the cause of light, for no contradiction follows from the above described oscillatory motion. It is not fitting for one grain of sand to hold the material which occupies the awful spaces between it and the sun. It is not fitting that the diamond should be nothing more than a thin, friable shell. It is not fitting to use the other contradictory ideas.

Secondly, the system is very satisfactory in that it offers a very clear explanation of the action and peculiarities of light and incontestably confirms different motions as the cause of heat and light.

It was shown above that rays from the lunar semicircle, concentrated by a burning mirror, do not show appreciable heat but have light at which we can scarcely look. This strange property will become clear and understandable from the above proposition. The particles of ether material between the sun and the moon move by oscillatory and rotary motions. The rotary motion is blunted by warming the surface of the moon, the oscillatory motion, which does not warm but serves to illuminate, loses less of its strength so that the reflected rays from our earth reach to the moon and return again from it, showing partial darkening of its side soon after the new moon.

Mercury in a glass vessel which does not contain air produces light without heat by falling in fine drops. It is well known to all that after a blow from a solid body spherical liquid drops quiver, contracting and expanding, so that the ether is also led into a quivering motion which produces light. Thus phosphors and other similar materials are lighted without radiating heat. Because of the shortness of time, this explanation will be sufficient for the present.

Now it is proper to explain my ideas on the reason for colors and to demonstrate their probability. But first, rather than describing it, I will show the basis which has been unknown to physics up to now; not only has there been no explanation, but there has not even been a name for the phenomenon which is so significant and widespread in all nature that it occupies the most important place in producing the properties that originate in insensible particles. I call this the *combination of particles.* The importance of this basis depends on the similarity and dissimilarity of the surface of the particles of the same and different sorts of primary materials which make up bodies.

Picture to yourselves the extent of the structure of the universe, which consists of insensible globules of different sizes, their surfaces covered with particles and fine inequalities by which these particles can cohere with each other like teeth on a wheel. It is known from mechanics that those wheels are connected and move each other whose teeth are of equal size and like arrangement, attuned to each other; and when the sizes and arrangement are different, then they are not connected and do not move each other. This I find in the insensible primary particles which make up all bodies, built up by the all wise Architect and all powerful Mechanician in accord

with immutable natural laws, and I call those particles which are connected to each other *compatible,* and those which are not connected and do not move each other, *incompatible.*

By operating on this basis, I can present clearly all the actions and other wonderful effects and changes which are observed by the senses to occur in nature.

Changes arising in the brain are announced by this motion through the vital juices in the nerves to their ends which are joined to the particles of external bodies touching them. This occurs in an insensible interval of time by continuous combination of particles along the whole nerve to the end in the brain itself. For it is known from the laws of mechanics that many thousands of such globules or wheels when they stand uninterruptedly joined in connection can be rotated from one external force from one surface, stopping when it stops and increasing or decreasing the speed of their motion along with it.

Thus the acid material contained in the nerves of the tongue combines with acid material particles placed on the tongue to produce a change in motion and this presents itself to the brain. Thus sensation is generated. So chemical solvents act, letting loose effervescence. In this way liquid materials rise in narrow tubes. Electrical force acts in this way and can be clearly presented, explained, and demonstrated without the aid of inflow and outflow of fluid and without assuming any cause contrary to the motion of sensible materials. We merely suggest that by friction on the glass there is produced in the ether a rotary motion of its particles by a superior speed or a shutting off of motion by the remaining ether. This motion spreads from the surface of the glass to the pores of water or metal suitable for it. Here we do not need an unknown flowing motion of the particles of ether, but only their slight rotation. Thus, while we cannot understand how a flowing ether from a small electric point passes so far in an insensible time, we can show here that by the application of an electrified hand to a nonelectrified body the compatible particles in whose pores there exists a mutual linking are turned by a rotary motion, so that the whole body in one instant produces an electrical oscillatory motion which increases its rate or changes its direction. At the same time, the rate of oscillatory motion becomes quieter in the electrified person because all bodies which communicate

motion to another body give it up; hence this decreases in it. It is contrary to mechanical law that there is a flowing ether of many lengths bent in all directions in innumerable forms but without repulsion and struggle, for due to the many million angles, it should here lose its motion. These difficulties are eliminated by assuming the rotary motion of compatible particles, for in spite of the angles between each bend and fiber, it can be freely produced. The electric spark and feeling of discomfort, the thunderous blow and the other effects and properties according to former explanations and up to now have remained more strange than clear. According to this system, the combination of particles becomes easy to understand mechanically. However, for brevity's sake I am permitted no further explanation, and beautiful colors bring my oration back from electrical thunder clouds.

All the unspeakably great number of ether particles mentioned can be divided into three types of different sizes, all of which have a spherical shape. The first type of particle is the largest and by continuous mutual contact has a square arrangement. Therefore, considering a cubic body as against a sphere of the same diameter doubled, there will remain almost as much empty space between these particles as the spheres occupy. In these spaces I assume ether particles of a second type, which, being much finer, are packed in considerable number against each other in a square position and by continuous mutual contact similarly occupy half the space in the interstices, hence the amount of material is half as compared to the first. Also I assume a third sort of the finest ether particles in the interstices of the particles of the second sort. This third sort of particle is of the same order of arrangement and by the above mentioned geometrical dimensions will have an amount of material in proportion to the amount of material of the second sort as one to two, to the amount of the first sort as one to four. There is no reason to divide the particles further nor do I see any necessity for this. These three sorts of ether particles are each connected with the other sorts and are incompatible with different sorts of particles so that when the parcles of the first type turn by a rotary motion, joining with the others of their type, a large number in the circle around them are moved by the force of cohesion. The second and third sorts

of particles will not be involved in this motion. This is, of course, also true of the other two sorts of particles. To speak briefly, the two sorts of particles can remain without turning while one is moved in a rotary motion; and when two turn, one can be motionless, and equally all three can be moved or all at rest without depending on each other.

Sensible bodies by classification and by the agreement of eminent chemists consist of primary material, acting or acted on; chief or subsidiary. The first is assumed to be salty, sulfurous, or mercurious material; the second, pure water or earths. They do not believe the ordinary salt, sulfur, and mercury to be the primary simple and unchangeable materials; they merely derive the names from the predominance in them of these primary materials.

I have made observations, and after many years by many surmises and also after definite experiments I have confirmed with sufficient probability that the three sorts of ether particles agree with the three sorts of true primary particles which make up sensible bodies, namely: the first size of ether corresponds to salt; the second size with mercury; and the third size with sulfur or inflammable material; and with pure earth, with water, and with air are joined all that is blunt, weak, and imperfect. Finally, I find that from the first type of ether arises the color red, from the second, yellow, and from the third, blue. Other colors are generated from mixtures of the first ones.

Now that we have seen the structure of these systems, let us look at their motions. When the sun's rays extend light and heat to sensible bodies, then the vibratory motion of the ether globules touches their surfaces and presses on them, and rotary motion is rubbed away from them. Thus the compatible particles of ether are joined to the compatible particles of the primary materials which make up the body. And when these are not suitable for rotary motion for some reason, then the rotary motion of this sort of ether is dulled; the vibratory motion still remains in force. Under such circumstances, the following phenomena occur.

When the mixed particles of any sort of sensible body are so arranged that each primary material has a place on its surface, then all the sorts of ether particles touch it, and by combina-

tion lose their rotary motion; therefore the rays of the sun without this motion do not produce any color in the eye, since they do not have the strength to induce rotary motion in the particles which compose the bottom of the eye. Thus the body appears black. Let us assume a mixed sensible body such that there is no single mixed particle of a predominant primary material on the surface, but this surface is surrounded by pure earthy or watery particles. Then all sorts of ether material should join only weakly with this, and the rotary motion would encounter scarcely any hindrance; hence with the rotary motion it acts on the bottom of the eye, producing all the colors sensible to the view, and such a mixed body has a white color.

Then let there be on the surface of the particles of mixed body a predominantly acid material; others are either not in the mixed body or they are covered by the acid. Then the first sort of ether material is deprived of rotary motion for combination with this and will not produce the sense of the red color in the eye, and only the yellow and blue ethers, rotating, begin to act freely in the optic nerve on the mercury and inflammable material and produce the sensation of yellow and blue light at the same time, from which such a body should be green. Equally when mercury is on the surface of the material a purple color is produced; when inflammable material is on the surface, a deep yellow color appears in the material.

When two materials have a place on the surface of the mixed particle, then from acid and mercury, the sensible color remains blue; from acid and inflammable principle, yellow, and from mercury and inflammable principle, red; since in the first case there is no inflammable material on the surface to hold back the blue ether; in the second no mercury to retain the yellow, and in the third, no acid to hold back the red ether.

Already you see my whole system of ideas on the origin of color; it remains finally to present the evidence and confirm that my proposed idea is more than a simple invention or arbitrary suggestion.

First, that a triple number of colors is required is confirmed by all previously known opinions of the professionals from numerous optical experiments by the famous physicist and industrious student of the nature of color, Mariotte, who did not refute Newton, as some thought, but tried to correct his

theory about the separation of light by refraction of the rays into colors and only confirmed that in nature there are three and not seven chief colors.

The different sizes of the particles and their arrangement as described above are required by nature itself, which must everywhere require this classification equally, so that everywhere the three sorts of ether will be in the same proportions and there will be no tendency or resistance to lose this nor will any sort fail to match the others. This I will show by very simple and comprehensible examples. Picture to yourselves some place filled with cannon balls so that no more can be packed in. However, there will be idle spaces between them which can be filled with a great multitude of fusilier bullets. The empty spaces between the bullets will be filled with small shot. In such a state, let the balls, bullets, and shot be set in motion, as much as they can be. The balls will remain everywhere in one proportion; the bullets thus in proportion will everywhere occupy their spaces between the balls; between the bullets the shot remains in equal measure. And thus there remains continuous contact between the three sorts of spheres. By such a method and only by this, is it possible to maintain everywhere an equal proportion in a mixture of the three types of ether. For if the ether differed in shape and heaviness, it would be impossible for it to be in an equilibrium mixture everywhere. Let us consider further the motion of the air, the waves of the sea, the annual and daily course of the earth, the rotation of the planets and comets; everywhere the ether remains in the same proportions in its mixture, in spite of tendencies and forces. There is no collection of each sort in one place, excluding the others. And this is impossible according to the arrangement described above. Under these circumstances it is what would be expected.

Nature is most surprising in that it produces uncounted forms, properties, changes, and phenomena with simplicity by its great skill from a small number of causes. Can there be a special kind of ether for reddish yellow, for green, for purple, and for other mixed colors when reddish yellow comes from red and yellow, green from yellow and blue, purple from red and blue, and other kinds of mixed colors from various other mixtures? The painter uses the chief colors and prepares others

by mixing; then in nature can there be a greater number of sorts of ether material for colors than it needs, since it always follows the simplest and easiest path for its actions?

Moreover, it appears in bodies destroyed by fire that light refracted by prisms shows with proper accuracy the threefold number of primary simple colors. When a candle, or wood, or any other body burns with a lively and free flame, we see at the corners of the fire red, in the flame itself, yellow, and between the corner and the yellow flame, blue; these are the primary particles of matter composing bodies set in rotary motion, and by the heat of the burning body itself the three sorts of ether are moved. At the corner the acid material moves, along with itself, the red ether; in the flame, mercury moves the yellow, and above the burning corner the sulfur moves, for it is rotated by the flame more easily and before the mercury, and the rotary motion leads to the blue ether motion. Thus everything takes place according to the greatest probability.

Pure alcohol contains a greater part of inflammable matter in itself, and aside from a little acid, no mercury has been found in it by anyone. When burning, it blazes with a blue flame, clearly showing that the burning material, turning in it by rotary motion is the third sort of ether which, joined with it, rotates and produces the sensation of a blue color. Mineral sulfur, besides containing inflammable material, contains acid, but no mercury and therefore the burning flame gives a purple color as it should according to this system. For in rotating, the particles of acid material lead to a rotary motion of the red ether which along with the blue can lead to a feeling of a purple color. The mercurious primary material should produce a yellow color according to the above theory. This is shown in artillery practice where for entertainment by the production of yellow flares they use antimony, a body rich in mercury material.

Phosphorus when it glows or burns with a flame shows a greenish color, which clearly corresponds to its mixture, for phosphorus consists of inflammable material and salty acidity which is mixed with mercury materials.

When, after melting, gold is cooled and begins to approach the state of a solid body, it shines with a very pleasant green

color. What then occurs in its mixture? The acid material first of all loses its rotary motion (for it requires the greatest heat), the other two, inflammable and mercurious, still have sufficient heat to turn the particles and so turn with a rotary motion which turns the ether of the second and third sorts and gives the sensation of yellow and blue together, that is, produces green.

A flame of a green color, though shown by many burning bodies, comes most of all from copper. It is enough to remark here that when this melts, the whole flame becomes green when fresh cold charcoal is thrown on it. This is for the same reason that cooling gold produces green, that is, the heat of the flame is decreased by the cold charcoal, the acid material of the hot copper loses its rotary motion force while the inflammable and mercurious materials are heated enough by the weak heat for motion. Thus without motion of the red ether, the yellow and blue present green to the sense of vision.

Thus art, which confirms my opinion by its agreement, shows the action of the primary materials when, rotating in a flame, they move the ether by rotary motion, and by combination produce different colors in the sense of vision. Now it remains to show how these are reflected from the surface of the illuminated body into the eye and how different combinations produce different colors. For this purpose, let us first consider the blackness and whiteness of tangible bodies, and then pass to colors.

When water boils it does not take great heat into itself. Hence its particles cannot reach equal speed by combining with others which produce motion in the surrounding material. Thus the ether particles which have no exact combination with the water located on the surface of the moving sensible particles come into view with surrounding motion of all three sorts of ether and arouse the sense of all colors, that is, the color white. But when a combustible white material, for example wood or paper, is touched by fire, it immediately blackens and is converted to charcoal. How does this come about? Water, which is in the mixed body, is driven out by the heat and the active primary material left exposed keeps the ether back from rotary motion by combination and this ether does not reach the eye and does not produce a sense of color, and thus it appears black to us. Hence it happens that a white sub-

stance is less heated by the sun and a black one is more heated. For all three sorts of ether material are caught in combination on the particles of a black body and submitted to rotary motion, while on a white body the opposite occurs.

A strong burning lens covered with black lacquer produces at the burning point a very great light and only a little heat, clearly showing that rotary motion of the ether in a black material is exhausted, the vibratory motion continuously remains.

Here you may ask, not without reason, whether I do not establish one cause for heat and color, which are such different phenomena. I answer that the motion which produces heat and color is rotary, the materials are different. The cause of heat is rotary motion of the particles which make up sensible bodies. The cause of color is rotary motion of the ether, which along with heat is communicated to earthly bodies from the sun. Heat and color are rather similar in their effects, but we see more if we examine closely both these properties in nature. For the present case it will be sufficient to make the new remark that colors of cold bodies appear brighter to the vision than those of hot bodies.

Take two pieces of the same singly colored material, especially a red one. Put one piece on a hot stone or iron, only so that it does not catch fire; the other in the cold, especially in the winter in a severe frost. You will see clearly that on the cold rock the piece of material is redder than on the hot one. This truth can be tested by changing the piece of material from the hot rock to the cold one, and from the cold to the hot as often as you wish. Other colors are not so sensibly changed.

Here we can see clearly that in cold bodies as the constituent particles are turned more quietly by a rotary motion, they more strongly hinder the ether. Those which are not on the surface of the mixed body leave free those which are not compatible on the surface, therefore these, separated from the others, seem brighter. On the other hand, the particles of the hot body move faster, the ether particles are not kept so strongly from rotary motion; therefore by their residual motion, the chief colors are formed and do not come so brightly to the vision. This I first concluded from my theory, and afterwards found it to be true by test.

Now it is time to look at all three kingdoms of multiform

nature so that even though we show it briefly, we will see how much similarity there is in the structures of animal, plant, and mineral substances within this system.

It is known from chemical experiments that in mixed bodies of animals there is very little free acid; therefore there is little green in them. Thus when animal parts are destroyed they do not turn sour, but loss of constituents occurs. By souring, acid and inflammable materials are liberated from a mixed body; by loss of material, mercurial particles are lost. Therefore in animals, acid primary material is surrounded by the others and produces little acid taste and green color.

Contrary to this, in plants greenness and acidity predominate; there is green in all the parts; acid is also felt there; in flowers acid and green are lost. Unripe fruit is acid and green; ripe fruit is blue, reddish, yellowish, or purplish, and different kinds become sweet when their acidity is either decreased or altogether suppressed.

When wood rots or leaves fall from trees they turn yellow; the mercurial material is driven off and separated from the mixed body, dispersing into the air. Hence the second sort of ether, that is, the yellow, not being joined to the surface, does not lose its rotary motion and, extending to our eye, produces this motion in the mercury material compatible with it in the black membrane at the bottom of the eye, and arouses the sensation of yellow in the optic nerve.

In the mineral kingdom of nature where there are many chemical changes, I could present a great number of examples which would confirm the correctness of my opinion, showing differences in minerals and in the chemical actions affecting color properties and effects. However, I cannot now put them all in my oration. Therefore I will offer a small part of these.

Water and pure earths and rocks have no other color than white, that is, all three sorts of ether are reflected without losing their rotary motion. This agrees with the above demonstration that they have little compatibility with the ether. On the other hand, black bodies are always composed of many different mixed materials and, being compatible with all the sorts of ether, hinder their rotary motion, without which no sort of sensible color can be excited in the eye.

I cannot remain silent here about the opinion, contrary to

daily experience, of those who, in assuming the spread of light in a flowing of the ether, produce blackness from a great number of pores which they ascribe to the black body and assert that light, entering them, disappears. According to their opinion, if a body has more pores it will be blacker than one with fewer pores. Therefore white chalk should be denser than black marble; pigments, darker when ground than when unground; facts which are contrary to nature.

An effect not like this, but in accord with my system as described above, is found in ink making. When the particles of the material composing ink are still freely separated in water, they move with a rotary motion and are scarcely hindered by the ether globules, and therefore the color does not have a marked darkness. But when the added materials are combined into one mixed particle, then all the mixed body particles will be large and little inclined to rotary motion; then all three sorts of ether are hindered in rotary motion which therefore does not reach the eye from these particles and no sense of color is produced; the mixed body appears black. The addition of aqua fortis whitens the ink since the acidity is comptaible with the material of the mixed body and separates it, and thus gives great freedom of motion; blackness is restored to the ink by alkaline salts; then the acid material taking this into the mixed body forms again the combined material which composes the ink.

Such combination of the primary particles composing a body into large particles of the mixed body occurs in all chemical mixtures when by removing the liquid from solutions the dissolved material combines with itself into coarse particles which settle to the bottom and produce different colors according to how much material occupies their surfaces.

Hence it happens that most acid liquid mineral substances do not have a green color, for they move freely in water and red ether is not hindered in rotary motion. But as fast as their acid particles for any reason become unfit for rotary motion, then, hindering the first kind of ether, the red color is extinguished and the blue and yellow remain free, producing a green color; for example, when so-called oil of vitriol (a material exceeding all else in acidity) thickens in a great frost and its particles have very little rotary motion, a green color is pro-

duced in it. Equally copper and iron above other metals congeal with acid materials which not only dissolve faster in them than in others, but also are destroyed in their vapors and show reciprocal combination of the particles of one sort; by combination into large particles these lose fitness for rotary motion by the acid and retain the red ether, so that their solutions and precipitates in pure acid oil of vitriol tend more to a green color.

I would like to show for this system all the examples from numerous experiments which I have carried out and studied especially on multicolored glasses for the mosaic art, and I would wish to explain everything that I have thought over fifteen years between my other tasks. But this would require a much longer time than is allowed for a public oration. Second, I would have to explain clearly to everyone my whole system of physical chemistry, to perfect and report it to the scientific world, which is prevented by my love for the Russian language, the great Russian heroes, and the search for the activities of our fatherland.[1]

Thus I now beg that this expression of my ideas on the origin of color will be received with willing and patient waiting for my whole system, if God permits. Especially I offer it to those who, because they turn with praise to chemical practice alone and do not venture to raise their heads above soot and ashes in order to seek the reason and nature of the primary particles composing bodies, from which color and other properties come, are to be considered vain and sophistical. For knowledge of the primary particles is as necessary in physics as the primary particles themselves are necessary for composing sensible bodies. How many experiments are there for this in physics and chemistry? How many great men have risked their lives and work for this? For this they have gathered together a great multitude of different substances and materials in confused masses, considered and wondered at their multitude, meditating on their arrangement and putting them in order.

Thus, when simple discoveries without any supporting evidence and without enough work to justify them have brought glory to many in the learned world, I have hoped that my system would be honored here with attention. The importance

1. [Lomonosov refers to his philological and historical studies, which were occupying most of his time at this period.]

of the material should produce this result. The greatest part of the freshness and joy in our lives depends on color. The beauty of the human face, of clothing and other decorations and implements, the pleasure of many colored minerals and precious stones, animals of different kinds, and finally all the radiant glory and beauty of the sun, everything that is produced in the magnificence of the blossoming fields, in the forests, and in the sea, are not all these worthy of our attention?

In briefly putting forth my ideas on this work for the present joyful celebration, my auditors, I have turned your hearts to radiant joy by this fitting subject of sunlight which enriches your eyes and hearts and does not leave you in darkness. The present festive day offers you the opportunity to voice your thoughts on this name day of Peter's daughter, the great Elizabeth, and on this day the Divine blessing, the good fortune, is doubled and multiplied, since it is also the name day of the Grand Dukes Peter and Paul. With you, my auditors, and with the general populace, the Imperial Academy of Sciences offers its felicitations and most humble testimony of gratitude and joy by a special public session. Oh how beautiful amidst our joy is the image of the springlike magnificence of our ruler! The image of majesty, power, glory, and all virtue of our incomparable monarchy. The image of indulgence to all, of mutual love and the other great gifts of the blessed pair, their Imperial Highnesses. The image of their beloved young children, the sweetest hope and expectation of our hearts. All your wishes, my auditors, and those of the fatherland burst forth with ours. Beautiful flowers, most dear, all kindly, sprung from the noblest roots of Europe, most brilliant Grand Duke Pavel Petrovich, bloom thou amidst the abundant spread of our garden of the whole Russian empire, renewed and surrounded by a strong wall through the immortal labors of your noble great-grandfather, adorned by the praiseworthy kindness and divine favor of his lawful descendant, zealous imitator, worthy daughter of such a father, our most gracious Sovereign. Grow thou in the radiance of a sun without beginning, delight us all by the fragrance of general joy, cheer our hearts and eyes by the unfading beauty of thy priceless health, reach unhindered to full maturity, increase the longed for fruit of thine inheritance to the eternal gratitude of the fatherland!

Criticism of the Theories of Lomonosov

The first volume of the *Novi Commentarii Academiae scientiarum imperialis Petropolitanae,* which contained several papers by Lomonosov, received considerable attention among the scholars of western Europe, and its contents were abstracted and discussed in many of the learned journals of the Continent. A highly critical series of comments on most of Lomonosov's theories appeared anonymously in the *Commentarii de rebus in scientia naturali et medicina gestis,* published in Leipzig. There is some reason to believe that the author was a certain Professor Kestner of Leipzig.[1] The following selection indicates the type of criticism contained in this journal.[2]

Mikhail Lomonosov in his work "On the cause of heat and cold" has reported nothing more than simple experiments. Beginning with the principle of sufficient reason he has painstakingly shown by this principle: *a sufficient reason for heat consists in motion,* and since motion is impossible without material, then *it consists in the motion of some sort of material,* here *an internal combined material.* We assume that the readers for whom the Academy publishes its reports would willingly consent to this as an axiom since this internal motion is not progressive, for particles of a solid body, strongly heated, do not notably change their position. He also denies the possibility of oscillatory motion of bound material, *since parts of the body cannot be bound by perceptible linkages if they compete by internal oscillatory motion.* He probably did not think of bells, the particles of which certainly vibrate on sounding, but the bell remains entirely solid for many centuries. Thus, nothing remains for him but to announce that heat is included in the *rotary* motion of the separate particles.

1. See the letter of Euler to Lomonosov of December 3, 1754, in G. E. Pavlova, *M. V. Lomonosov v Vospominaniyakh i Kharakteristikakh Sovremennikov* (Academy of Sciences Press, Moscow and Leningrad, 1962), p. 127.

2. *Commentarii de rebus in scientia naturali et medicina gestis,* 1:222-226, 228 (1752); 2:322-323 (1753); the selections translated here are given in Pavlova, *Lomonosov,* pp. 153-154, 161, 165-166, 177-178.

He asserts that for confirmation of his idea he uses the mathematical method of demonstration, *in which the a priori method is usually strengthened by examples or the a posteriori is tested,* as the mathematicians would say, so that it is confirmed by *rational* deductions obtained from experiments which never follow the exactness of geometry. Thus first of all, he turns to heat caused by friction and assumes that when one body is moved by another and the particles of the moving body plunge into the particles of the other body, both particles are set in motion. Let us assume that the rotary motion can occur only in the case when all the particles of the bodies are spherical, as the author depicts them in his figures. But the sphericalness of all the separate particles of the heated body are more easily drawn than shown to the eye of the physicist. It is known that Descartes considered whether all particles created by God were cubic and their rotary motion continued until their angles were rubbed off and they became spherical. But in our time when even the wisest physicist knows very little about the definite shape of the finest particles, it seems we cannot assume that all these particles can be spherical or that friction has such force and the spherical nature comes constantly from all other particles. However, the author immediately explains why strong compression and rapid motion cause strong heating, since in his opinion, they strengthen rotary motion, and why liquids are not heated by friction more than occurs among solid bodies; they prevent the heat which usually arises from friction since their particles are less cohesive and do not obtain rotary motion from friction, and as to this the reader can easily judge for himself after our account. Finally, he comes out against heat material which, in the opinion of others, is the source.

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Further, the same author follows with a *dissertation on the action of chemical solvents in general.* He considers that acids dissolving metals introduce air into the pores of metals, for indeed there is air in the pores of metals whose tension is already without activity, but with the inflow of new air it is as it were reactivated and the air bursts out, pushing apart the particles of the metal. He reports the finding that solutions are formed more quickly if there is more air in the liquid

than when we remove it with a pump, other conditions being equal; and he should also show that if the liquid is exposed to open air it is pressed to the metal by atmospheric pressure while in the vacuum of the pump this force is weakened and the liquid invades the pores of the metal with less force than under such pressure. For solution of salts in water he assumes another reason; indeed the pores of salt are full of water which does not contain air, but in water itself he does not deny the presence of air. Thus, water acts on the salt, exciting its particles to rotary motion, and this separates them from each other. Accomplishing this, *they themselves lose as much rotary motion and are therefore cooled.* Hence he considers one solvent *direct,* as the solution of salt in water, and the other *intermediate,* that is, by exciting the elastic force of air, as in the solution of metals in acid, and suggests that thus they can be differentiated by the sign of cooling or heating. But we cannot briefly express our opinion and we leave it to the reader to judge.

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The same Lomonosov has attempted to create *a theory of the elastic force of air.* He assumes that the particles of air are spherical, but denies that the elasticity can arise from interstitial fine fluid. But this fluid is either compressed or not compressed by air confined in any sort of vessel. If we assume the first, then the walls of the solid vessel should be impervious to this liquid, that is, its particles should be scarcely less than the particles of air, which contradicts the hypothesis. Therefore the fluid itself will act on the vessel, and it will not be necessary that particles of air be suspended in it. And still, which we consider most important, particles of this liquid will tend to withdraw from each other, which again requires an explanation. If the liquid is not compressed, then since it does not show any action on the solid walls of the vessel, it also does not act by any force on the finest particles of air, escaping due to its lightness and volatility. Finally, on compression of air and pushing out of some particles of fluid, a lesser number is left and if elasticity of air results from these, the compressed air should be less elastic. Thus it seems to him doubtful that

the elasticity of air results from direct action of its atoms, and since the elasticity of air is increased by heat, he considers the origin of the action is from heat alone, and this again on his hypothesis of rotary motion. He explains it thus: there are two particles of air, one above the other at a very small distance; by the force of gravity the upper falls on the lower and as it falls, both particles acquire rotary motion in contrary directions, for example, one to the right, the other to the left. These particles are not smooth, but somewhat rough. Thus when the projections of the upper particle falls in the hollows of the lower, motion arises from the blow in each and they recoil from each other; this is elasticity and it is directed in different directions, since at each blow the particles are repelled in a given direction or, because of the irregularities, they rebound reversibly from all the blows. He further makes suggestions about sound and about air included in bodies which it is not necessary to consider here, since the truth of this hypothesis can easily be judged. Without any basis he assumes rotary motion of each separate particle on a blow contrary to another blow, and also "for the spirit" he devises some story that in a series of particles lying vertically on each other all rotate alternately, one to the right, the other to the left. Then, if all the particles have weight and fall, under the influence of gravity, yet not one will strike another, since gravity communicates to all one and the same speed and it is then necessary to devise some other force which would hasten the upper and slow the lower, and finally, all the fluids with particles capable of rotating, that is all the fluids by the hypothesis of the author, which can be heated will thus have elasticity. For although the particles touch each other, yet the rotary motion gives them a tendency to go apart from each other. The author is left only one conclusion, to devise for water and other nonelastic fluids a higher degree of smooth elements, that is, to dissolve the hypothesis into another hypothesis.

The physicomathematical class includes Lomonosov's Supplement to the Dissertation on Elastic Force of Air. Here he speaks chiefly of the property of elasticity of air that its force is proportional to the density of air. But what the author says is very difficult to shorten so that it could be inserted here.

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Lomonosov wrote *on metallic luster.* He calls metals lustrous and ductile bodies of which the nonprecious are those which by action of fire are converted into ashes or glass, losing luster and ductility; the precious are those like gold and silver which resist the strength of fire for a long time; that which is removed on burning and glass formation is more volatile and since it colors metals as it were a lustrous color, this can be called the luster of metals. It is first of all considered to be inflammable substance or phlogiston. It is pushed out on burning, and on reduction to the metal form it is added again. Although this is observed only in the nonprecious metals, it can be seen even in gold, as the author asserts, for iron or copper regulus of antimony contaminated on melting by the phlogiston of iron or copper give gold a redder color. So also we find a large amount of sulfur in very hot and very cold regions which now, the author states, serves for formation of metals. He substantiates this for sulfur by various arguments and findings; he speaks further about the mineral acid and the arsenic principle which with phlogiston forms the so-called luster or more or less lustrous color of metals. If the illustrious author would strengthen his opinions by different experiments, he could assert this with more probability and could render aid to the artisans who are occupied with changing the nature of metals, that is, by adding concentrated phlogiston, carefully purified from contaminants to nonprecious metals they could drive out the impure luster, making them more precious. But those who have studied concentrating phlogiston and its addition to other bodies can easily understand how vain are the hopes of enriching these metals.

Dissertation on the Duties of Journalists in the Accounts Which They Give of Works Intended to Maintain the Liberty of the Philosopher

Lomonosov was so disturbed by the criticism which his theories received in the West that he determined to answer his critics and to define what he felt were the duties of those who criticized scientific papers. Accordingly he wrote this dissertation in Latin in August 1754. On November 28, 1754, he sent it to Euler with the request that the latter find a publisher for it and arrange for a general scientific discussion of the Lomonosov theories. Euler replied that it would be difficult to organize such a discussion, which in any case could not be very productive. However, he turned the manuscript over to his friend, the secretary of the Berlin Academy of Sciences, J. H. S. Formey, who translated it into French and published it in the journal which he edited in Amsterdam.[1] The French text (followed by a Russian translation) is published in *Collected Works,* III (1952), pp. 202-216.

No one is unaware of how rapid and considerable has been the progress of science since it has thrown off the yoke of servitude and followed it with the liberty of the philosopher. But neither can we any longer be unaware of the abuse of this liberty because of the very troublesome evils whose numbers would not have been nearly as great if most of those who wrote had not made more of a trade and breadwinning occupation of their work than of attempting an accurate and well regulated search for truth. It is from this that there have come so many dangerous matters, so many bizarre systems, so many contradictory opinions, so many aberrations and absurdities that science would long ago have suffocated under this enormous mass if the company of scholars had not combined and

1. *Nouvelle Bibliotheque germanique, ou l'histoire litteraire de l'Allemagne, de la Suisse, et des pays du Nord,* pt. 2, 7:343-366 (1755).

utilized all their forces to oppose such a catastrophe. We can see from this that the torrent of literature carries on its waters both the true and the false, the certain and the uncertain, and that the philosopher runs the risk of losing all his authority if he does not withdraw from this situation; he has formed societies of men of letters and has erected a sort of literary tribunal designed to appreciate the work and to give to each author full justice according to the most exact rules of natural law. This is equally the origin of the academies and of the organizations which preside over the publication of their journals. The first take care, before the writings of their members appear, to submit them to a rigorous examination which assures that they do not mix error with truth, that they do not give mere hypotheses for proofs, or old ideas for new. The duty of the journals is to present brief and accurate reports of the works which appear and sometimes to add a balanced judgment to them, either on the basis of the material itself or on some matter concerning the execution. The purpose and use of abstracts is to spread the knowledge of books rapidly throughout the republic of letters.

It would be superfluous to indicate here how much service the academies have rendered to science by their assiduous work and scholarly memoirs, how much the light of truth has been extended and fortified since their salutary establishment. The journals could also have greatly favored the growth of human knowledge if their authors could have fulfilled all the tasks which were imposed on them and had been willing to remain within the just limits which these tasks required. The strength and the will, these are what they need; the strength to discuss in a firm and scholarly manner the great number of different subjects which come within their scope; the will to see nothing but the truth, to yield nothing to prejudice and passion. Those who set themselves up as journalists without these talents and without this disposition would never accomplish their results if, as has been suggested, they had never felt the spur of hunger and had not been forced to consider and judge that which they did not understand. It has come to the point that there is no work, however bad, which has not been praised in some journal, and conversely, there is nothing, however excellent, which has not been cried down and reviled by some ignorant or un-

just critic. Then too, the number of journals has multiplied so that there is not time even to read the useful and necessary books or to consider and work with them for anyone who might wish to collect and merely glance over the Ephemerides, Learned Gazettes, Literary Acts, Libraries, Commentaries, and other periodical products of this sort. Intelligent readers, too, apply themselves to those which are recognized as better and shun all those miserable compilations which only copy and often mangle what others have already said or whose only merit consists in distilling spleen and venom without moderation and without reserve. A learned journalist, penetrating, equable, and modest has become a sort of phoenix.

In order to justify what I have suggested, I am more embarrassed by the crowd of examples than by the lack. The one on which I will base the rest of this dissertation is a sort of journal which is published at Leipzig to report on work in physics and medicine.[2] Among other things, it has given an account of the Memoirs of St. Petersburg, but there can be nothing more superficial than this account, which has omitted the most remarkable and the most interesting matters and complains that the Academicians have neglected facts or details which are perfectly well known to men of the profession and which it would be a ridiculous affectation to display, especially in matters which have not been submitted to the rigor of mathematical demonstrations.

One of the worst reviews, conforming least to the rules of sane criticism, is that on the memoirs of Councilor and Professor of Chemistry Mikhail Lomonosov, in which such a mass of errors has been made as to merit notice so as to teach critics of this sort not to step out of their sphere. At the beginning, the journalist announces his purpose; he threatens, the thunderbolt forms in the clouds and prepares to burst forth. Lomonosov, he says, *wishes to proceed to something greater than from experiments alone.* As if a scientist does not have the right to rise above the routine and technique of experiments and is not called upon to subject these to reason so as to pass from them to discoveries. It is as if a chemist, for example, should be compelled always to hold the tongs in one hand and

2. Its title is *Commentarii de rebus in scientia naturali et medicina gestis.*

the crucible in the other and never for an instant turn aside from charcoal and ashes.

The critic then tries to subject the Academician to ridicule for making use of the principle of sufficient reason and to have sweat blood and water, as he expresses it, to apply in demonstrations of truth that which had already been proposed as an axiom. At least he says he has taken them for such; but at the same time he rejects the most obvious propositions as pure fiction and thus contradicts himself. He mocks at rigorous demonstrations when they are necessary and demands them when they are superfluous. It is for the philosophers who wish to avoid mockery to see how they take something to show nothing and at the same time to show everything.

The motion of bells is a subject on which the journalist exercises his criticism without any foundation. He reproaches Lomonosov for not having given a true idea. Can anyone judge with more temerity? Is it lack of understanding, of attention, or of justice when he speaks thus? The critic confuses the internal movement of the bell with its total movement, two things which are completely distinct, and no one can take the vibration of the bell for its internal movement after the Academician has said so positively in §3 of his memoir that internal movement consists in change of position of the insensible particles. When a bell is swung, when it is rotated, when it passes from one place to another, these movements have nothing in common with its internal movement and consequently cannot be regarded as a cause of heat. Actually, when a bell vibrates, the parts are in vibration with the whole. It is when an entire body has a progressive movement; all the parts move at the same time, but there is no internal movement, and this is the case with the vibration of the bell. Let the critic know that internal movement is not attained by vibration, but when vibrating particles of a body change their positions with relation to each other in an imperceptible interval of time (§3, 6) and consequently act and react on each other in a very rapid manner. However, this cannot occur in any body unless the particles are free of cohesion, which we assume for the particles of air in studies of its elasticity. Let the same critic recognize that no one violates the law which he wishes to impose on others more than he himself, the law which expounds well

the first principles which serve as an explanation of a subject.

A progressive motion or a vibration, then, cannot be a cause of internal motion, and it would be impossible for the critic to persist in his error in this respect if he knew that bells which ring and are struck with great force are no less cold. He thus does not understand himself, and is most mistaken when he blames the author for having established rotary motion as the cause of heat.

There is no more basis when he reasons on the ground of §14 of the memoir of Lomonosov that mathematicians never follow the *a posteriori* method for confirming truths already demonstrated. Is it not certain that in geometry, as elementary as it is sublime, numbers and figures are used to explain the theorems and somehow to put them before us, and that in mathematics applied to physics experiments are constantly used to support demonstrations? No one who has the slightest knowledge of mathematics can deny this. Wolff has even made this a law in his *Arithmatic,* §125.[3] Therefore it is disgraceful for a judge to ignore or neglect such a law.

The journalist is more correct when he denies that rotary motion can occur in particles which are not endowed with spherical shape, but he is then in agreement with the opinion of the author. Thus it is an evil quibble that he is made to say that he has not formally expressed this assertion when it comes as an immediate consequence of the doctrine of §13, and there cannot be the shadow of a doubt that the rotary motion which produces heat in the basic matter of the body has at once shown that the particles of this matter must necessarily be spherical. Besides, philosophers of the first rank usually conceive of primary particles as spheres, and I believe they are correct. For, if one bases anything on the argument by analogy, one can scarcely find any example more striking than what we find in the matter in question. Nature obviously chooses roundness in large things as in small ones, and we can observe this in the immense bodies of the whole universe and in the little globules that swim in the blood. In the various parts of animals and plants, in eggs, fruits, seeds, is any other shape encountered

3. Here are his words: Therefore we teach what is stated and we perceive that truth corresponds to experiments deduced *a priori.*

more often than the circular? And for liquid bodies, without even excluding melted metals, spherical drops are constantly formed, as round as they are small. This is enough to permit the idea that the elementary particles are also globular, but there is no lack of stronger reasons to make this fact still more evident. We certainly need not be stopped for fear that there cannot be an infinite variety of things unless there is also accepted variety in their principles: for the size, the position, the place are enough to explain this diversity. But I will not pretend to give the judge a physics lesson here; I wish only to warn the one who has this function that he should not hasten to carry out the sentence without having examined well the culprit, nor delight in seeking faults where there are none.

For instance, do the scholars who today apply themselves to the study of nature reconcile themselves to the decision which comes from its tribunal? Today the judicious physicists do not pride themselves that they know the definite shapes of the particles. This certainly would not be to the taste of a Robert Boyle who has said that knowledge of the particles was as necessary in natural science as the particles themselves are necessary in nature for the formation of bodies. All the physicists of some reputation who have followed this celebrated Englishman have not diverged at all from his opinion; and they could not have done so without opening the door to the strangest consequences. We could as well say that we could learn to read without knowing the letters of the alphabet or determine the state of astronomy in the sky without any previous study of geometry. We have always considered it important to obtain a more exact knowledge of the shape of the particles. And even if we are not entirely successful, we have shown more leniency than our critic, all of whose words are judgments and proscriptions.

In his report on the "Dissertation on the Elastic Force of the Air," we do not know if the journalist has dreamed or has wickedly invented what he makes the author say, that the corpuscles of the air are *smooth,* an expression of which there is not the least trace in the work. He would seem to have confused the word *levitas* which occurs in §11 and which signifies the specific lightness with *laevitas* which has the meaning *smooth.* When someone reads so badly, he should not even

report to his readers, much less take such a haughty tone and say: But these particles are not smooth but a little rough. Zoilus is permitted to battle against these smooth corpuscles, but he should remember that he is battling against himself and these chimeras are purely his own invention.

Let us pass to another dictatorial shaft, so ridiculous that it hardly merits mention. "This rotary motion of each particle in a direction opposite to that of the other," says the critic, "is an entirely gratuitous supposition and has the air of a fable invented to please." What then can we say of this nonsense? Are we not permitted to propose particular examples to illustrate universal laws? Lomonosov reports in §16 a case which, though rarely encountered when atoms of air strike each other, is not less real, and there are others which are similar in effect, that is, where the touching surfaces of two corpuscles tend at the same speed in the same direction. Other sorts of collision are further from these and have more force to produce mutual repulsion of the particles. However, the fury of the critic and his condemnation are still shown by the journalist and he continues in these terms.

"If all the particles are heavy and fall because of gravity, it will never happen that one will strike the other by falling on it since gravity impresses the same rate on all, and it is necessary to assume some other force which accelerates the upper one and slows the one below." Here we can say that the critic loses ground and sinks into pure imagination. For we who do not wish to leave the surface of the globe know very well that the surrounding atmosphere presses on this surface. This is why the lower particles of air cannot descend farther; the atmosphere prevents their fall. These in turn resist the particles which lie on them and there are successive collisions with these up to the surface of the atmosphere. There is no need to make an effort of the imagination to invent a new force which slows the particles when they fall from the air. Enlightened and just judges have no need of this warning, but we must say this for ourselves.

An absurdity which he pretends to deduce from the theory of the elasticity of the air proposed by the Academician is that all fluids are no less elastic than air; and he adds, quite gratuitously, that no other resource is left to the author than to

conceive of the elements of water and of nonelastic fluids (as he is pleased to call them) as reduced to an extreme degree of smallness and thus to save one hypothesis by the help of another. Strange sagacity in a man who pursues the most imperceptible trifles and who does not see the most obvious things when they are before his eyes. He has not deigned to pay the least attention to the elastic vapors of water and other liquids, nor to the cohesion which exists between their particles. Moreover, daily experience shows to everyone who wishes to notice that water does not show an elasticity like that of air as long as the mutual cohesion of its parts lasts, that is to say, as long as the repulsive forces do not exceed the strength of cohesion. But as the rotary motion continuously increases, the repulsion finally begins to exceed the cohesion, and water passes into a vapor with the greatest elasticity. This is what Lomonosov has shown clearly in his "Dissertation on the Cause of Heat," §23, but the haste of the critic has led him to leap over this point. From this then, according to the theory of the author, the rough particles not only can enter the composition of water and other liquids, but also into the production of elastic vapors, and it is useless for the critic to change them into particles of extreme lightness.

Finally he turns his guns on the Dissertation which concerns the action of chemical solvents. There, without considering the reasoning or making any logical deductions, he speaks at random. We can see how little he understands his reading or how to capture the essentials of what he reads by the tacit avowal that he has not cast his eyes on §28 which contains the true essence of the memoir. If he had actually known this paragraph, could he have said, "The author should consider that when a solvent is exposed to the air it is pressed toward the metal by the weight of the atmosphere and this force ceases entirely in the vacuum of the pump, etc." But nothing is clearer than the description in the paragraph mentioned of the solution of copper in aqua fortis made not in a vacuum, but in the open air. And for the experiment described in §29, though it was made in a vacuum, there the notable difference in metal dissolved confirms the theory of the author against the attack of the critic, the more so that at the end of the same paragraph the reason for this difference is given.

Up to now we have given incontestable proofs of the incapacity and of the extreme negligence of the journalist. But here is a point where his good faith is entirely suspect and where he appears to have designed formally to impose on the learned world the thought that the Memoirs of the Imperial Academy at St. Petersburg is a rare work which no one is able to consult. Confident of this, he then dares to attribute to the Academician a degree of ignorance, the denial of the existence of air in the pores of salts, which even the greatest novice in physics could not fail to know was wrong. It is as if he had no means of deducing anything from similar dissertations of the author, whatever violence he did to them, and the result is quite natural. For the words of §41 cannot be given the above meaning: they are *air dispersed in water does not enter the pores of salts. To enter* was never synonymous with *to be contained.* The Academician wished to say and could not wish to say anything else except that air did not enter from the water into the salts which it had dissolved. And it is not conceivable that this could be transformed into the assertion *the pores of the salts do not contain any air.*

It must be very painful for the journalist to admit that Lomonosov has given a very happy explanation of the movement of air in mines, for it is in spite of himself that he is forced to concede this. However, he pretends still that it is defective in some respects. There are two points that he remarks. First, he believes that he can scarcely admit that the temperature of the air remains the same for a long time at the bottom of the shafts. He is right, if he means a temperature exactly the same. But he should know that this is not a case of such a nature that we can apply the perfect rigor of geometric measures which cannot and should not apply. Thus the author has the right to suppose that those who live in mines can remain for a long time without noticing changes coming from the outside air. The critic says further that others who have examined the same phenomenon have reported that changes which come from the air into mines have no relation with winter and summer and that they depend uniquely on changes in atmospheric pressure at the same season of the year. In this respect anyone who is aware of the laws of aerometry and hydrostatics could never be persuaded if anyone told him

that similar observations had never been made. For when the weight of the atmosphere is increased or diminished the increase or decrease in pressure are equal and synchronous at such little distances as occur between two shafts. And indeed, if there actually were such differences in time and pressure, they would be so small and of such short duration that there would not occur any effect able to disturb the movement in the mines. But if there happened on summer days to be a cold approximating that of winter, or in the days of winter a summer warmth, then it would be quite natural (and no one would be surprised at it) that the exchange in the outside air would be less apparent at the bottom of the mine, as Agricola has already noted. Since all this is of a nature which can be most easily understood by intelligent men, we need not trouble to show the greater difficulties and to aspire to a degree of precision which means nothing in the present case and to formulate a useless theory which would have to be abandoned in practice.

We must not forget a last mark of that rapidity which our judge believes he can combine with his severity, though these are incompatible. He imagines that Lomonosov in his "Supplement to the Reflections on the Elastic Force of Air" has chiefly wished to examine *that property of the elastic air by which its force is proportional to its density.* He deceives himself and deceives others in making this judgment. With a little more attention he could have seen that here the question is precisely the contrary and that it is affirmed that there is needed for condensing the air a compressing force much more considerable as the air is dispersed in more narrow limits; from which it results that the densities are not proportional to the forces.

Can there be a more authentic conviction of all the defects which can lose for a journalist the credit and confidence which he hopes to obtain from the public? Can anyone with even a trace of shame and a residue of conscience justify such behavior? For when anyone reports in this way the work of men of letters, he not only does harm to their reputations for which he has no right, but he stifles truth in presenting to his readers ideas which have no relation to those of the author, and it is natural to oppose forcefully such unjust behavior. If anyone continues thus to treat those who seek to benefit the republic

of letters, he will completely discourage them and the progress of science will be greatly slowed. This would be the complete destruction of the liberty of the philosopher. We must mark for such critics the proper limits within which they should confine themselves and which they cannot overstep with prudence. Here are the rules with which we conclude this dissertation, and we beg the journalist of Leipzig to remain in accord with them.

1. Anyone who intends to inform the public what new works contain should first consider his power. He undertakes a very laborious and complicated task, for the point is not to report common things and simple generalities, but to pick out what is new and essential in works which are often those of great men. To report these things without justice and without taste is to expose them to scorn and laughter; this is like a dwarf who wishes to raise up mountains.

2. To put oneself in a position to render a sincere and equable judgment, it is necessary to banish all prejudice, all predispositions of mind, and not to pretend that the authors with whom we meddle should servilely confine themselves to the ideas which dominate us, regarding those who are without these as true enemies on whom we must declare war.

3. The writings on which we report should be divided into two classes. The first includes those which are the work of a single author who has written as a private person; the second those of whole societies published by their common consent and after a careful examination. Both certainly deserve all the circumspection and regard of the critic. Every work deserves that we observe the natural laws of equity and decency. But we should insist that the precautions should be doubled when we deal with works which already bear the seal of a respectable approval, which have been reviewed and judged worthy of appearance by men whose collective knowledge should naturally be superior to that of a journalist, and before he ventures to condemn, he must weigh more than once what he wishes to say before he can sustain and justify it if the case requires it. As these kinds of writings are usually worked up carefully and the materials are treated systematically in them, the least omission or inattention can render judgments dangerous which by themselves are already discreditable, but which become

more so when negligence, ignorance, haste, partisan spirit, and bad faith show themselves in an evident manner.

4. A journalist should not hasten to decry hypotheses. They are allowed in philosophical matters, and it is the only way in which great men have come to discover the most important truths. They are a type of soaring of the mind which has led to gaining knowledge such as abject spirits, creeping in the dust, never reach.

5. A journalist should especially learn that there is nothing more dishonorable for him than to steal from some of his colleagues the reflections and judgments which they have proposed and to take the honor to himself when he scarcely knows the titles of the books which he tears to pieces. This is very often the case with a rash writer who decides to undertake the abstracting of works on physics and medicine.

6. A journalist is allowed to refute what appears to him to deserve this in new works even though this is not his direct object or his own vocation, but when he does this, he should properly state the doctrine of the author, analyze all his proofs, and oppose them with real difficulties and solid reasoning before he arrogates to himself the right to condemn. Simple doubts and arbitrary questions do not give him this right, for no one is ignorant of the fact that it is possible to formulate many more questions than the most expert man can answer. Above all a journalist should not imagine that what he does not understand and cannot explain also holds for the author who may have had reasons for shortening and omitting certain things.

7. Finally, he should never gain too high an idea of his superiority, his authority, and the value of his judgments. Since the function which he exercises is already by itself disagreeable to the self esteem of those who are its object, he would be entirely wrong to displease them willingly and to force them to bring to light his deficiencies.

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